NOS. DOT-TSC-NHTSA-77-2

HS-802 324

SPECTRAL ANALYSIS OF THE EFFECTS OF DAYLIGHT SAVING TIME ON MOTOR VEHICLE FATAL TRAFFIC ACCIDENTS

Norman J. Meyerhoff

U.S. DEPARTMENT OF TRANSPORTATION
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

REPRINT

AUGUST 1978

FINAL REPORT

DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
NATIONAL HIGHWAY TRAFFIC SAFETY ADMINISTRATION
Office of Research and Development
Mathematical Analysis Division
Washington DC 20590

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
HS-802 324		

4. Title and Subtitle
SPECTRAL ANALYSIS OF THE EFFECTS OF DAYLIGHT SAVING TIME ON MOTOR VEHICLE FATAL TRAFFIC ACCIDENTS

5. Report Date
REPRINT August 1978

6. Performing Organization Code

7. Author(s)
Norman J. Meyerhoff

8. Performing Organization Report No.
DOT-TSC-NHTSA-77-2

9. Performing Organization Name and Address
U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

10. Work Unit No. (TRAIS)
HST23/R6410T

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
National Highway Traffic Safety Administration
Office of Research and Development
Mathematical Analysis Division
Washington DC 20590

13. Type of Report and Period Covered
Final Report
June 1975 - August 1976

14. Sponsoring Agency Code
NHTSA/NRD31

15. Supplementary Notes
NHTSA Program Manager and State Data Coordinator: Henri A. Richardson/NHTSA

16. Abstract

This report shows that Daylight Saving Time (DST) reduces the number of persons killed in motor vehicle traffic accidents by somewhere between one and two perent. This estimate is based on a spectral (Fourier) analysis of these fatalities which utilizes a filtering technique to identify that part of the fatality frequency spectrum which is sensitive to DST while suppressing all other frequencies. To establish a cause/effect relationship between DST and changes in the filtered fatality time series, the changes are measured in two ways: (1) Across DST transitions and (2) For corresponding dates in years with and without DST. Certain statistical criteria are then applied to these measurements in order to confirm the existence of a DST effect on accidents and fatalities.

17. Key Words
Daylight Saving Time (DST), Motor Vehicle, Accident, Fatalities, Sunrise and Sunset Times, Fourier Analysis, Spectrum, Frequency, Filter, Time Series, Statistics, Trends, Bandwidth

18. Distribution Statement
DOCUMENT IS AVAILABLE TO THE U.S. PUBLIC THROUGH THE NATIONAL TECHNICAL INFORMATION SERVICE, SPRINGFIELD, VIRGINIA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	140	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

PREFACE

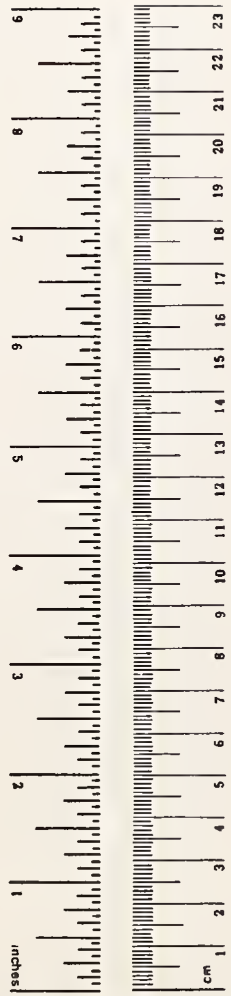
In 1973 Congress authorized the Secretary of Transportation to investigate the possible impact of Daylight Saving Time (DST) on a number of important aspects of the economy, one of these being motor vehicle traffic accidents. As a consequence of this authorization, the Department of Transportation, through its Transportation Systems Center (TSC), undertook a study of the overall nationwide impact of DST, including its effect on fatal traffic accidents. One of the findings of this earlier study was that DST reduces persons killed in motor vehicle traffic accidents by approximately 0.7 percent.[1]

The data base used for this earlier project consisted of selected extracts from the National Highway Traffic Safety Administration's (NHTSA) Fatal Accident File (FAF). This is a computer-automated file containing, at the time of the project, a near-census of all motor vehicle fatal traffic accidents occurring in the United States from January 1973 through June 1974. However, for this earlier project, only a few statistical tests could be made to determine the impact of DST on fatal accidents. Therefore, in support of the obligation of the Secretary of Transportation to Congress, the NHTSA requested the Transportation Systems Center to perform another study of DST and traffic accidents and analyze more recent data obtained from the States specifically for the DST project. This report discusses the findings of this second study.

METRIC CONVERSION FACTORS

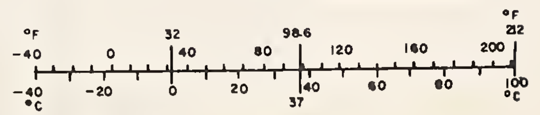
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. SUMMARY

This report analyzes the effect of Daylight Saving Time (DST) on motor vehicle fatal traffic accidents (hereafter referred to as fatal traffic accidents) by examining differences in numbers of persons killed (fatalities) as a result of these accidents during DST and non-DST periods. Changes in fatalities were measured across four DST transitions and one control (nc DST) transition. In addition, annual fatalities were compared for two years, one year with and the other without DST. In every test, evidence of a DST effect on fatalities was confirmed. Based on an observed 2.20 percent increase in traffic fatalities during January and February of 1973 and 1975 (when DST was not in effect), compared to the same period of 1974, when DST was in effect, and a fatality increase of 1.09% when transitioning from DST to Standard Time in October of 1973 and 1974, it is concluded that DST reduces the number of persons killed in traffic accidents by somewhere between one and two percent. These are average figures representing the combined results of both this study and the earlier Congressional study. The data base used for the present study is a near-census of total U.S. motor vehicle traffic fatalities occurring from October 7, 1973, through May 5, 1974, and from October 6, 1974, through May 4, 1975.

Although DST is expected to produce a similar reduction in all motor vehicle traffic accidents and, as a consequence, in

persons non-fatally injured in these accidents, this hypothesis could not be verified in the present study due to the insufficient sample of injury data available for analysis for the time periods indicated. However, analysis of available data gave some indication that reductions in all traffic accidents and injured persons are associated with DST, but a much more comprehensive injury data base would be required to perform a fully reliable quantitative assessment of the extent of this reduction.

2. INTRODUCTION

Motor vehicle accident data normally reflect various trends according to differences in the occurrence of accidents on a daily, weekly, monthly, seasonal, etc. basis. These trends are observable in the data as low and high frequencies. Typically, the high frequency content in data that are collected or summarized at intervals of about one week or more will be suppressed, and only the low frequency information will remain. If the sampling interval is one day or less, the data will contain both high and low frequencies. High frequency data generally contain more detailed information on the nature of motor vehicle traffic accidents but are more difficult to collect and process. The accident trends represented by these high and low frequencies are substantially independent of one another, as are ultraviolet and infrared light, which have different optical properties. The more recent accident data collected by the NHTSA expressly for this DST project contain only low frequencies in the traffic fatality spectrum (0.004 - 0.07 cycles per day), whereas the earlier study[1] had analyzed only high frequency data (0.2 - 0.5 cycles per day). Since, regardless of length of time interval, fatalities occurring at low and high frequencies are essentially independent of one another, as mentioned above, all results of this second study using the more recent accident data are independent of, and in

addition to, those reported in Reference 1. To have collected additional accident data with high frequency content would have required considerably more resources than were available at the time, for the project. In a sense, the second study has been more difficult to perform than the earlier one because of special problems for low frequency data that do not occur at higher frequencies (See Sections 4.1, 5.5, 5.6.3).

Although the same basic philosophy and methods of data analysis were used in both studies, there are certain basic differences between the two that should be noted, such as:

(1) Significant differences in data bases used.

(2) Variation in analytic procedure as a result of these differences.

(3) The present study extends the mathematical foundations of the analytic procedure which is common to both studies.

(4) The results of each study apply to separate and distinct data frequency bands.

(5) The present study also attempts to analyze the effects of DST on nonfatal traffic accidents.

The remainder of this report discusses the findings of this special DST study, along with the methods and assumptions used in arriving at the results obtained, as follows:

<u>Section</u> 3: Describes the DST model which hypothesizes the reduction effect of DST on fatal accidents and associated fatalities.

<u>Section</u> 4: Describes those properties of fatality data which tend to preclude identification of the relatively small number

of DST-related fatalities, and summarizes the usage of Fourier spectra to analyze trends in fatality data.

Section 5: Explains the criteria for the selection of the analytic methods used in the study and describes these procedures in detail, specifying how they are based on Fourier analysis and digital filtering. This section also contains an assessment of fatality data which shows how intrinsic properties of these data necessarily limit the degree of accuracy in the results of the analysis.

Section 6: Discusses the data used for this study; uses material from Section 4 to show how specific tests to determine the effects of DST were planned.

Section 7: Describes the numerical techniques used in data reduction and shows how these are influenced by the conclusions stated in Section 6. This section also summarizes the results of digital filtering.

Section 8: Estimates reductions in fatalities due to DST.

Section 9: Gives a summary of the statistical significance of DST-related fatality reductions.

Section 10: States the principal conclusions and recommendations of the study.

Section 11: References.

Appendix A: Presents a brief summary of the relationship between motor vehicle nonfatal traffic accidents and Daylight Saving Time.

Appendix B: Applies the same Fourier methodology to non-DST related traffic fatalities by interpreting certain fluctuations in the Fourier spectrum not related to DST.

3. THE DAYLIGHT SAVING TIME HYPOTHESIS

This section presents the model that relates DST to motor vehicle traffic accidents. DST-associated accidents are viewed as being primarily related to weekday rush-hours and other short-term trips occurring at similar hours throughout the week. Also, for generally the same set of conditions (e.g., driver, vehicle, traffic, roadway, weather, etc.), traffic accidents are much more likely to occur at night, that is, when there is less daylight. Therefore, since DST causes a difference in the amount of daylight present during the morning and evening hours of the day, it is hypothesized that DST affects the occurrence of traffic accidents at these times and, as a consequence, the number of persons killed or injured in these accidents. A transition to DST is hypothesized to increase morning accidents since there is one hour less daylight in the morning, and to decrease evening accidents since there is one hour more light in the evening. However, because of more traffic and consequently more accidents in the evening compared to the morning, particularly during weekday rush-hours, a transition to DST is hypothesized to result in a net decrease in daily traffic accidents. Conversely, a transition from DST to Standard Time (ST) is expected to decrease morning traffic accidents and increase evening accidents, resulting in a net increase in daily traffic accidents.

Hypothesizing that DST-related traffic accidents are light-dependent implies that they are also dependent on local sunrise-sunset times. Table 3-1 summarizes sunrise-sunset times in selected cities for each time zone. For instance, on November 1, most sunrises and sunsets thoughtout the United States occur near the peak of the morning (7a.m. - 9a.m.) and evening (4p.m. - 6 p.m.) rush hours. It should therefore be possible to detect any significant differences in fatalities related to the transition from DST to Standard Time which occurs around this time. The first study of the effect of DST on fatal traffic accidents did indeed varify this hypothesis, and these findings are included in the final Report to Congress on the overall nationwide impact of DST.[1]

On the other hand, a transition from Standard Time to DST in the vicinity of March 1 should indicate very little connection between DST and fatalities resulting from evening accidents. This is so because most cities in the U.S. at this time experience sunset after the peak of the evening rush hour, whether on Standard Time or DST. However, following this transition, there should be a detectable change in fatalities occurring during the morning rush hour because, around March 1, many cities experience sunrise between 7 a.m. and 9 a.m. Table 3-1 summarizes sunrise-sunset times in selected U.S. cities for each time zone and, using data from this table, Figures 3-1 through 3-3 superimpose the average sunrise and sunset times

TABLE 3-1 SUNRISE AND SUNSET TIMES FOR 24 CITIES THROUGHOUT THE U.S.

		SUNRISE							SUNSET						
		Nov 1	Dec 1	Jan 1	Feb 1	Mar 1	Apr 1	May 1	Nov 1	Dec 1	Jan 1	Feb 1	Mar 1	Apr 1	May 1
EASTERN TIME ZONE															
Boston, Ma.	Standard	6.17	6.54	7.14•	6.58	6.20	5.27	4.40	4.38	4.13	4.22	4.58	5.34	6.10	6.44
	Daylight	7.17	7.54	8.14•	7.58	7.20	6.27	5.40	5.38	5.13	5.22	5.58	6.34	7.10	7.44
Detroit, Mich.	Standard	7.06	7.42	8.02•	7.47	7.09	6.17	5.29	5.27	5.02*	5.12	5.48	6.23	6.59	7.32
	Daylight	8.06	8.42	9.02•	8.47	8.09	7.17	6.29	6.27	6.02*	6.12	6.48	7.23	7.59	8.32
Cincinati, Ohio	Standard	7.05	7.38	7.57•	7.45	7.11	6.23	5.40	5.38	5.16*	5.26	5.59	6.30	7.01	7.31
	Daylight	8.05	8.38	8.57•	8.45	8.11	7.23	6.40	6.38	6.16*	6.26	6.59	7.30	8.01	8.31
Washington, DC	Standard	6.35	7.07	7.27•	7.15	6.41	5.53	5.11	5.08	4.47*	4.57	5.29	6.01	6.31	7.00
	Daylight	7.35	8.07	8.27•	8.15	7.41	6.53	6.11	6.08	5.47*	5.57	6.29	7.01	7.31	8.00
Atlanta, Ga.	Standard	6.56	7.24	7.42•	7.34	7.07	6.26	5.49	5.46	5.29*	5.40	6.09	6.34	6.58	7.21
	Daylight	7.56	8.24	8.42•	8.34	8.07	7.26	6.49	6.46	6.29*	6.40	7.09	7.34	7.58	8.21
Miami, Fla.	Standard	6.29	6.50	7.08•	7.05	6.44	6.12	5.44	5.39	5.29*	5.41	6.04	6.22	6.37	6.52
	Daylight	7.29	7.50	8.08•	8.05	7.44	7.12	6.44	6.39	6.29*	6.41	7.04	7.22	7.37	7.52
CENTRAL TIME ZONE															
Bismarck, N.D.	Standard	7.25	8.07	8.28•	8.08	7.23	6.23	5.29	5.28	4.57*	5.05	5.46	6.28	7.12	7.52
	Daylight	8.25	8.07	9.28•	9.08	8.23	7.23	6.29	6.28	5.57*	6.05	6.46	7.28	8.12	8.52
Chicago, Ill.	Standard	6.22	6.58	7.18•	7.03	6.26	5.34	4.48	4.45	4.21	4.31	5.06	5.41	6.16	6.48
	Daylight	7.22	7.58	8.18•	8.03	7.26	6.34	5.48	5.45	5.21	5.31	6.06	6.41	7.16	7.48
Kansas City, Mo.	Standard	6.46	7.18	7.38•	7.25	6.52	6.03	5.20	5.18	4.56*	5.06	5.39	6.11	6.42	7.11
	Daylight	7.46	8.18	8.38•	8.25	7.52	7.03	6.20	6.18	5.56*	6.06	6.39	7.11	7.42	8.11
Amarillo, Tex.	Standard	7.08	7.37	7.56•	7.46	7.17	6.34	5.56	5.52	5.35*	5.45	6.15	6.42	7.08	7.32
	Daylight	8.08	7.37	8.56•	8.46	8.17	7.34	6.56	6.52	6.35*	6.45	7.15	7.42	8.08	8.32
Little Rock, Ark.	Standard	6.29	6.58	7.16•	7.08	6.39	5.56	5.19	5.15	4.58*	5.09	5.38	6.05	6.30	6.54
	Daylight	7.29	7.58	8.16•	8.08	7.39	6.56	6.19	6.15	5.58*	6.09	6.38	7.05	7.30	7.54
New Orleans, La.	Standard	6.14	6.38	6.56•	6.51	6.27	5.58	5.18	5.14	5.00*	5.12	5.37	5.59	6.19	6.37
	Daylight	7.14	7.38	7.56•	7.51	7.27	6.58	6.18	6.14	6.00*	6.12	6.37	6.59	7.19	7.37
MOUNTAIN TIME ZONE															
Great Falls, Mont.	Standard	7.09	7.52	8.13•	7.52	7.07	6.05	5.09	5.09	4.37*	4.45	5.26	6.10	6.55	7.37
	Daylight	8.09	8.52	9.13•	8.52	8.07	7.05	6.09	6.09	5.37*	5.45	6.26	7.10	7.55	8.37
Rapid City, S. D.	Standard	6.28	7.07	7.27•	7.10	6.30	5.34	4.44	4.43	4.15	4.25	5.02	5.40	6.19	6.55
	Daylight	7.28	8.07	8.27•	8.10	7.30	6.34	5.44	5.43	5.15	5.25	6.02	6.40	7.19	7.55
Salt Lake City, Ut.	Standard	6.58	7.32	7.52•	7.38	7.02	6.12	5.27	5.28	5.01*	5.11	5.45	6.19	6.52	7.24
	Daylight	7.58	8.32	8.52•	8.38	8.02	7.12	6.27	6.28	6.01*	6.11	6.45	7.19	7.52	8.24
Denver, Col.	Standard	6.28	7.02	7.21•	7.08	6.34	5.45	5.01	4.58	4.36*	4.46	5.19	5.52	6.24	6.54
	Daylight	7.28	8.02	8.21•	8.08	7.34	6.45	6.01	5.58	5.36*	5.46	6.19	6.52	7.24	7.54
Albuquerque, N.M.	Standard	6.27	6.56	7.15•	7.06	6.36	5.54	5.16	5.13	4.55*	5.06	5.35	6.02	6.28	6.52
	Daylight	7.27	7.56	8.15•	8.06	7.36	6.54	6.16	6.13	5.55*	6.06	6.35	7.02	7.28	7.52
Phoenix, Ariz.	Standard	6.46	7.14	7.32•	7.24	6.57	6.16	5.40	5.37	5.20*	5.31	5.59	6.25	6.48	7.11
	Daylight	7.46	8.14	8.32•	8.24	7.57	7.16	6.40	6.37	6.20*	6.31	6.59	7.25	7.48	8.11
PACIFIC TIME ZONE															
Spokane, Wash.	Standard	6.34	7.17	7.39•	7.17	6.31	5.29	4.33	4.33	4.01	4.09	4.51	5.35	6.20	7.02
	Daylight	7.34	8.17	8.39•	8.17	7.31	6.29	5.33	5.33	5.01	5.09	5.51	6.35	7.20	8.02
Portland, Ore.	Standard	6.50	7.30	7.51•	7.32	6.50	5.51	4.59	4.58	4.29*	4.38	5.17	5.57	6.39	7.17
	Daylight	7.50	8.30	8.51•	8.32	7.50	6.51	5.59	5.58	5.29*	5.38	6.17	6.57	7.39	8.18
Reno, Nev.	Standard	6.27	7.00	7.20•	7.07	6.32	5.44	5.00	4.58	4.36*	4.46	5.19	5.51	6.23	6.53
	Daylight	7.27	8.00	8.20•	8.07	7.32	6.44	6.00	5.58	5.36*	5.46	6.19	6.51	7.23	7.53
San Francisco, Cal.	Standard	6.35	7.06	7.25•	7.14	6.42	5.55	5.14	5.11	4.51*	5.02	5.33	6.03	6.32	7.00
	Daylight	7.35	8.06	8.25•	8.14	7.42	6.55	6.14	6.11	5.51*	6.02	6.33	7.03	7.32	8.00
Los Vegas, Nev.	Standard	6.03	6.33	6.52•	6.42	6.11	5.27	4.48	4.45	4.26*	4.37	5.07	5.35	6.02	6.28
	Daylight	7.03	7.33	7.52•	7.42	7.11	6.27	5.48	5.45	5.26*	5.37	6.07	6.35	7.02	7.28
Los Angeles, Cal.	Standard	6.12	6.40	6.59•	6.50	6.22	5.41	5.04	5.00	4.44*	4.55	5.23	5.49	6.14	6.37
	Daylight	7.12	7.40	7.59•	7.50	7.22	6.41	6.04	6.00	5.44*	5.55	6.23	6.49	7.14	7.37

Notes: Cities in each time zone listed from north to south

••••••Latest sunrise within 1 minute of this time

○ Latest sunrise in time zone

******Earliest sunset within 3 minutes of this time

○ Earliest sunset in time zone

for January 1, 1974, November 1, 1974 and March 1, 1975, respectively, on the average hourly percentage distribution of traffic volume for the 4-week periods centered on these dates.[2] The average sunrise and sunset times shown are expressed in terms of both ST and DST for the same day. Since, in all these cases, a major traffic peak occurs between 4 p.m. - 6 p.m. and a secondary peak occurs at 7 a.m. - 9 a.m., it is hypothesized that a transition to or from DST will have its maximum effect on accidents if sunrise occurs between 7 a.m. - 9 a.m. and sunset occurs between 4 p.m. - 6 p.m.

The foregoing hypotheses are verified in Section 8 which summarizes changes in the number of traffic accident fatalities as a result of the DST transitions of October 28, 1973 and October 27, 1974, and those of January 6, 1974 and February 23, 1975. It must be especially noted that no measurable effect of DST could be detected for the evening hours, 4 p.m. - 6 p.m., of the latter transition, as predicted by the DST hypothesis. There are additional implications of the DST hypothesis, as follows:

1. Following a transition to DST, there should continue to be fewer traffic accidents and resulting fatalities compared to the same period on Standard Time, as long as sunrise and sunset continue to occur in the proximity of the peak rush hours.
2. Traffic accidents and resulting fatalities should be somewhat more sensitive to the presence or absence of DST

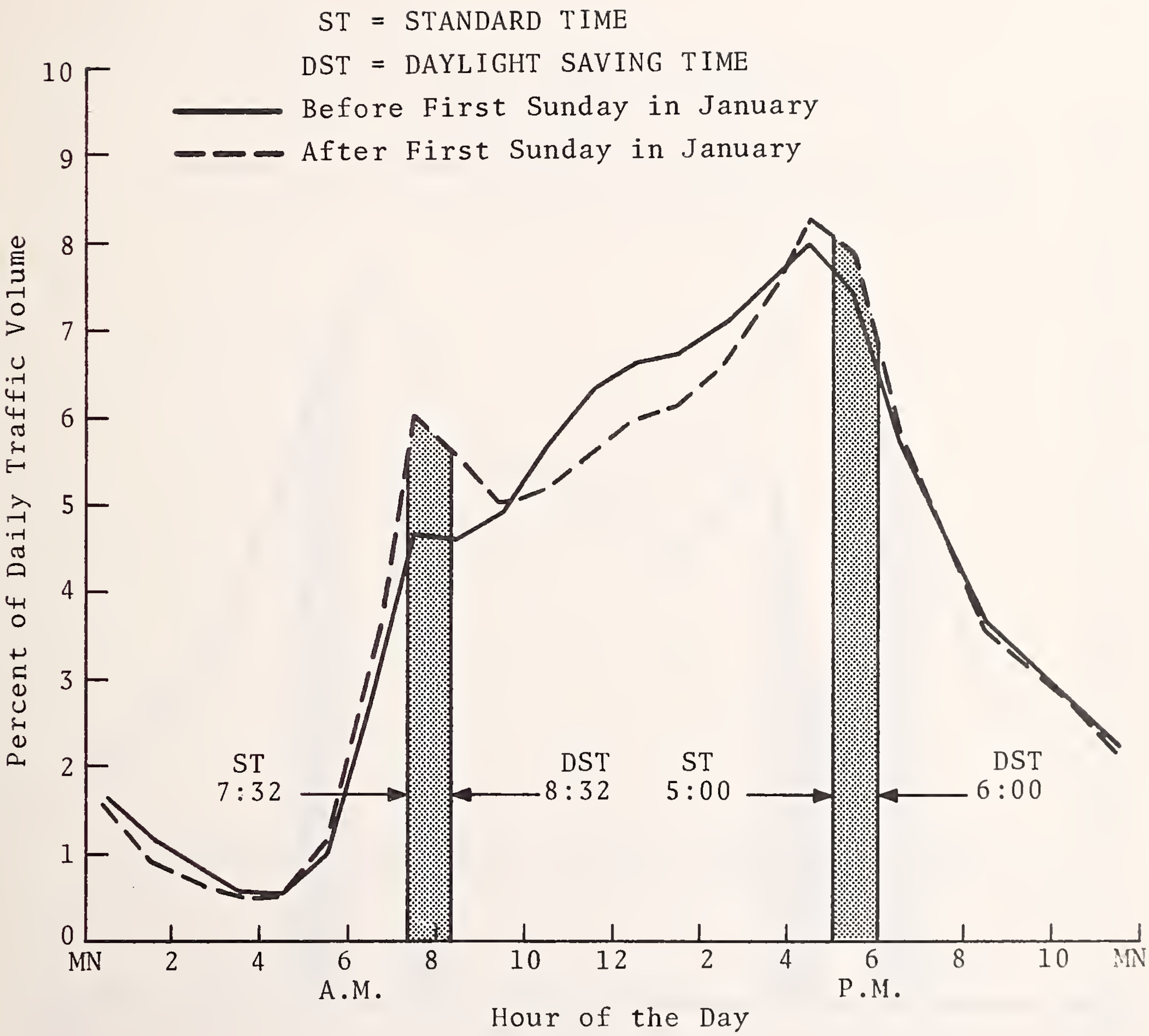

FIGURE 3-1. TYPICAL HOURLY TRAFFIC DISTRIBUTION IN U.S. FOR TWO-WEEK PERIOD IMMEDIATELY BEFORE AND AFTER WINTER TRANSITION TO DST ON JANUARY 6, 1974 (FHWA). Times shown are U.S. Average Sunrise-Sunset Times for January 1, 1974 Based on ST and Assumed DST for This Date.

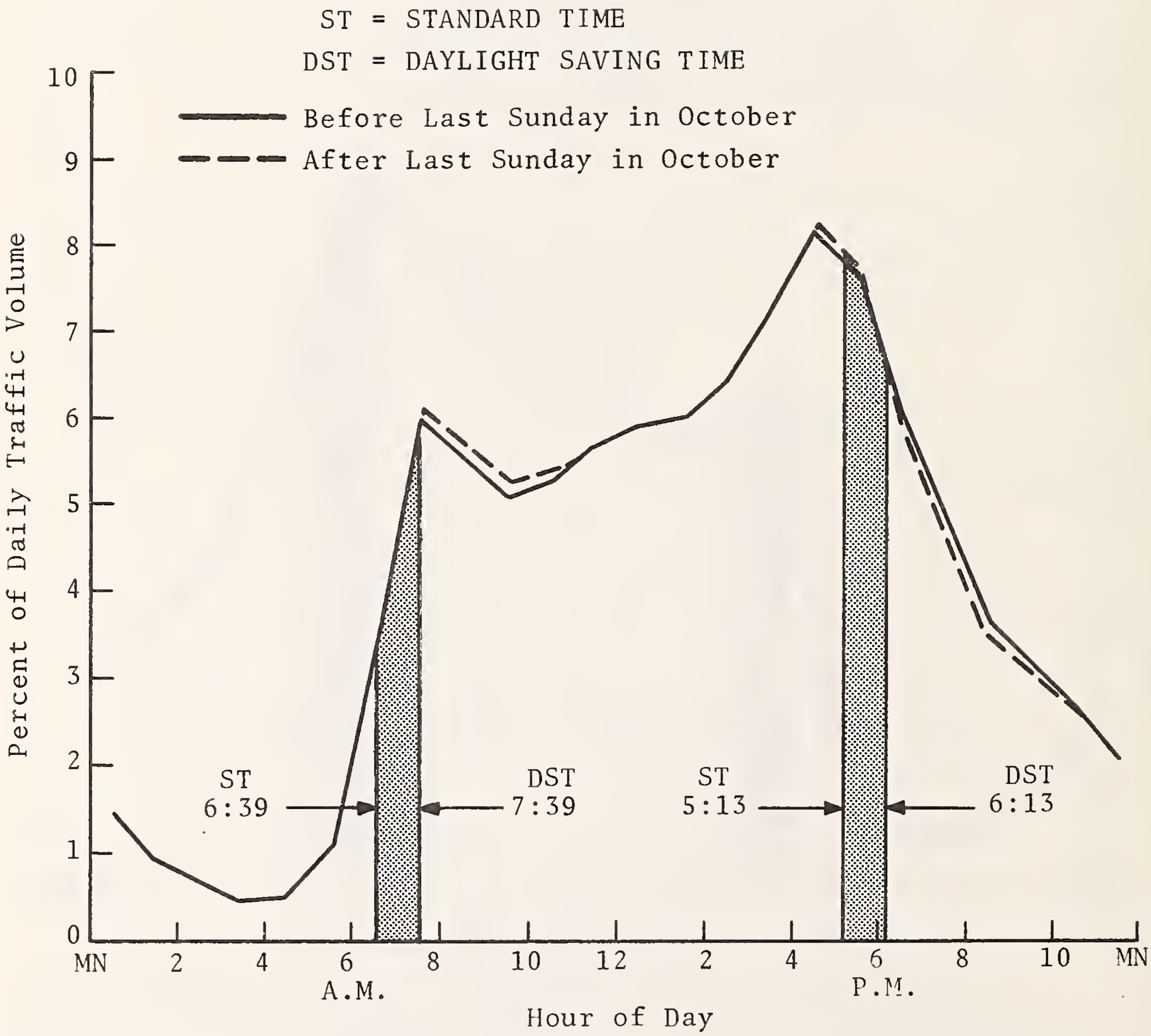

FIGURE 3-2. TYPICAL HOURLY TRAFFIC DISTRIBUTION IN U.S. FOR TWO-WEEK PERIOD IMMEDIATELY BEFORE AND AFTER FALL TRANSITION FROM DST TO ST ON OCTOBER 27, 1974 (FHWA). Times Shown are U.S. Average Sunrise-Sunset Times for November 1, 1974 Based on ST and Assumed DST for This Date.

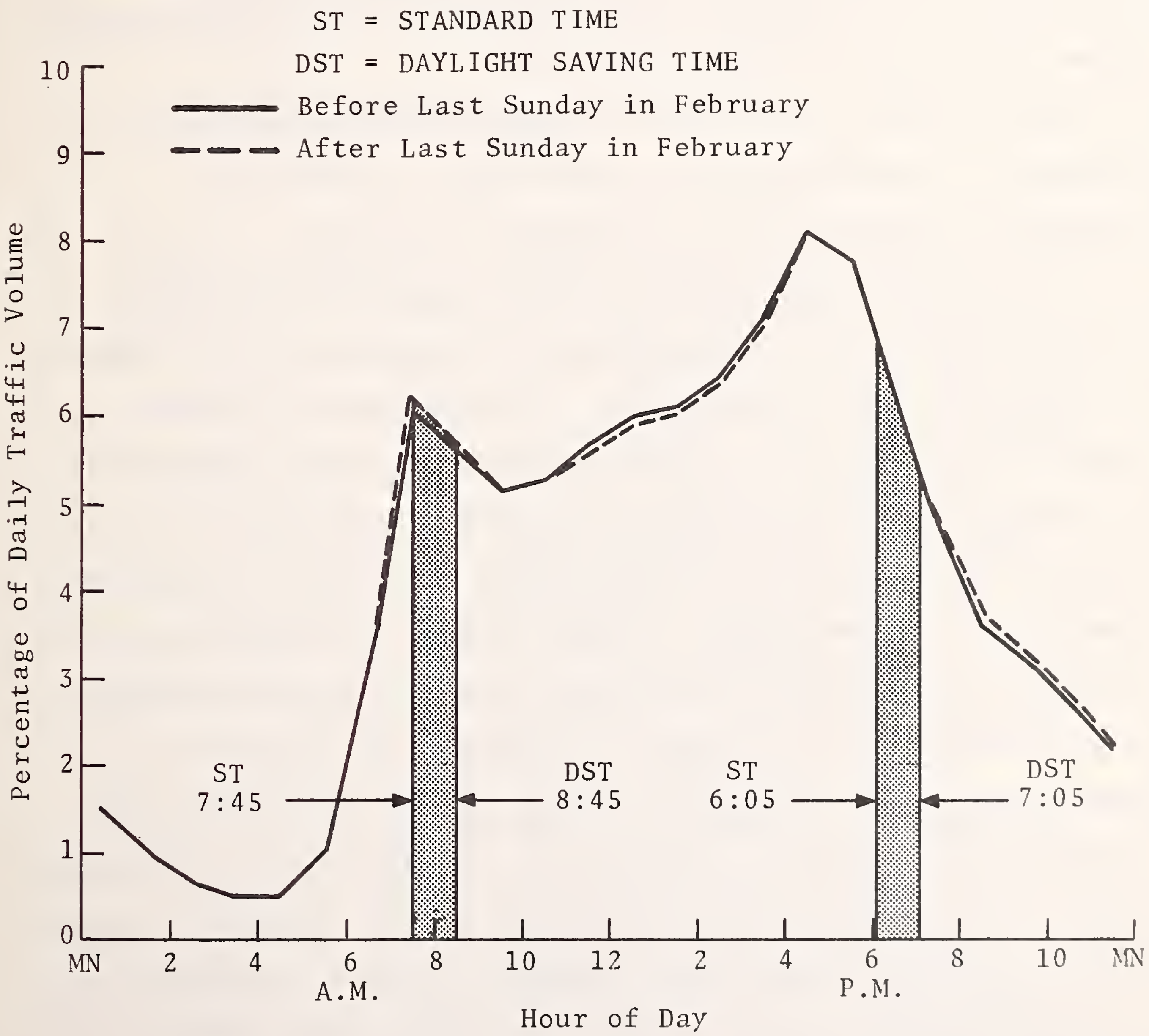

FIGURE 3-3. TYPICAL HOURLY TRAFFIC DISTRIBUTION IN U.S. FOR TWO-WEEK PERIOD IMMEDIATELY BEFORE AND AFTER SPRING TRANSITION TO DST ON FEBRUARY 23, 1975 (FHWA). Times Shown are U.S. Average Sunrise-Sunset Times for March 1, 1975 Based on DST and Assumed ST for This Date.

during the weekday rather than the weekend. This hypothesis was actually verified in the earlier Congressional study[1], but could not be tested in the present study due to time constraints which permitted only sampling of total weekly rather than daily or hourly fatalities.

3. DST influences both fatal and non-fatal motor vehicle accidents in substantially the same manner. Appendix A estimates the effect of DST on non-fatal accidents.

4. It is not only the amount of light that influences motor vehicle accidents at a transition, but also the rate of change of traffic across the transition. For example, the morning transition in Figure 3-2 has more statistical significance than the evening transition (Section 9) because the traffic distribution changes more rapidly across the shaded area in the morning than it does across the shaded area in the evening. If the slope of the traffic distribution curve is changing rapidly at a transition, the DST effect on accidents is easier to measure than if the slope were smaller because additional (DST-related) high frequency components are introduced into fatality spectra (see Section 4 and Section 5.4). It is therefore easier to discriminate between accidents related to DST and those not related to it. It should be noted that a higher level of significance is not necessarily correlated with an increase in DST-related accidents.

4. CHARACTERISTIC TRENDS IN TRAFFIC FATALITY TIME SERIES

This Section describes the basic properties of the traffic fatality time series and their Fourier spectra.

4.1 TRAFFIC FATALITY TIME SERIES

Section 3 hypothesized that motor vehicle traffic accidents are related to DST because of the varying amount of daylight present during the morning and evening hours of the day as a result of DST or Standard Time. However, many other factors also influence the occurrence of traffic accidents and associated fatalities. If these factors cause significant differences in the number of accidents occurring in the proximity of DST transitions, then the problem of distinguishing between the relatively small changes in fatalities due to DST is greatly complicated.

As an example, for many years the United States normally went on DST at the end of April and off DST at the end of October. However, the large seasonal increase in fatal accidents during the spring of the year (April - May) should more than offset any decrease in fatal accidents caused by the spring transition to DST. Likewise, the magnitude of the hypothesized increase in fatal accidents when the nation goes off DST in October may be small in comparison with the seasonal

decrease in these accidents which often occurs at this time (October - November).

Unfortunately, seasonal variations in traffic accidents are not the only phenomena that serve to obscure relatively small changes in accidents directly related to DST, for there are other types of trends. An important example is the weekly trend, where fatal accidents are at a minimum during the week (Monday - Thursday) but at a maximum on weekends, beginning Friday night. In this connection, note that the nation always converts to DST on a Sunday. Therefore, the hypothesized decrease in fatal accidents as a result of DST is no doubt obscured by the characteristic increase in fatal accidents on weekends and the characteristic decrease on Monday and Tuesday following. The findings of the earlier study[1] indicate that there are also other trends occurring monthly, biweekly, etc., and analysis of all such trends would require a separate study by itself. However, all of these trends have at least one thing in common: collectively, they involve many more traffic accidents than the relatively small changes in the occurrence of these accidents as a result of DST.

The usual approach in studying traffic accidents over a period of time, as with most other time series, is to try to identify the trend and analyze it.[3] However, this approach is not productive for analyzing the DST-related variations in traffic accidents since these are very small perturbations

superimposed on a much broader trend. Whereas a conventional trend analysis will remove or in some way suppress the small perturbations in order to reveal the trend, the present study requires just the opposite, that is, that the broad trend be removed and the remaining small perturbations in accidents be identified and analyzed.

The immense diffuculty of this problem is illustrated by Figure 4-1, which is a computer-generated plot of fatalities occurring every day between 4 p.m. - 10 p.m., for the first six months of 1973, for the entire U.S. These data were used in the first study of DST and traffic accidents[1] and several trends are easily identifiable. A six-month trend is observed to originate from the lower left hand corner of the plot and to extend along an approximate diagonal to the upper right. This trend can be imagined as an "average" line running halfway between the troughs and crests of the plot. Each trough and succeeding crest is a weekly trend whereby the trough represents weekday fatalities and the crest represents fatalities occurring on the weekend. The (approximate) periodic nature of these troughs and crests is very striking. Additional trends with different periodicities may be identified by careful examination of this plot of raw data, while others can be seen only by examination of the associated frequency spectrum, which is a mathematical representation in frequency space of traffic fatalities in temporal space that

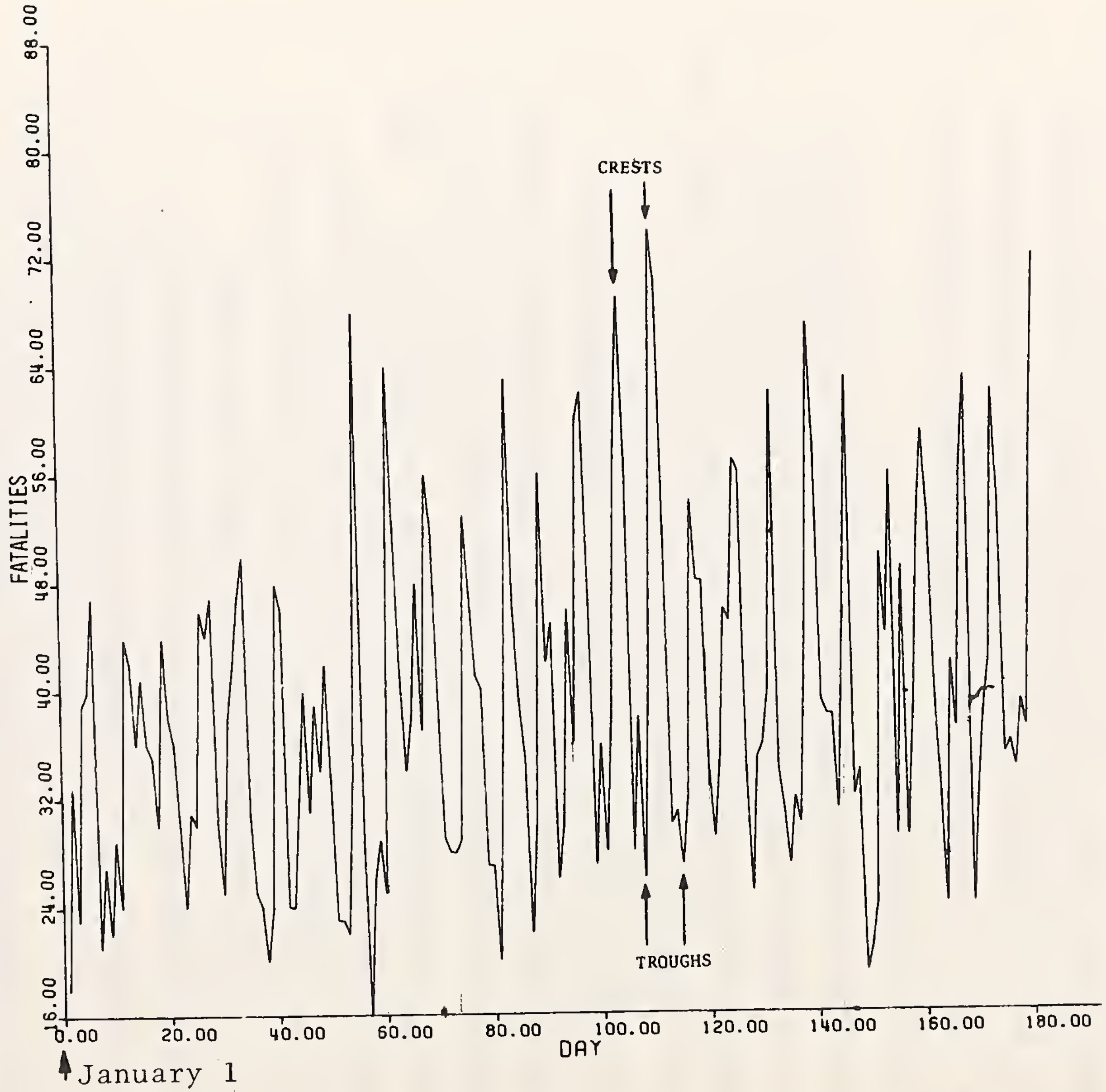

FIGURE 4-1. TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, FIRST SIX MONTHS, 1973, 4PM-10PM.

provides a measure of how rapidly the fatality trends change in temporal space.

The large variations in this composite six-month trend, which are due to all of these individual trends, completely obscure any immediately obvious effects of the transition to DST which, for the six months represented, occurred on day number 120 (i.e., Sunday, April 29, 1973). In fact, the overall fatality trend continues to increase beyond the transition date, which would appear to contradict the DST hypothesis.

However, each individual trend, which is strongly influenced by different accident populations, generates a different characteristic frequency in the data. Thus, the six-month trend generates the frequency 1/180 = 0.006 cycle/day (CPD); the weekly trend generates the frequency 1/7 = 0.14 CPD.

Figure 4-2 is the frequency spectrum of all data shown in Figure 4-1. That is, the data of Figure 4-1 have been mathematically transformed by the Fourier technique such that each different trend of raw data (Figure 4-1) now becomes a trough or crest of the plot in Figure 4-2. For example, the weekly and bi-weekly characteristic trends of Figure 4-1 are now easily discernible at 0.14 CPD and 0.28 CPD, respectively, in Figure 4-2. For the earlier study[1], all frequencies smaller than approximately 0.2 CPD were removed because their large

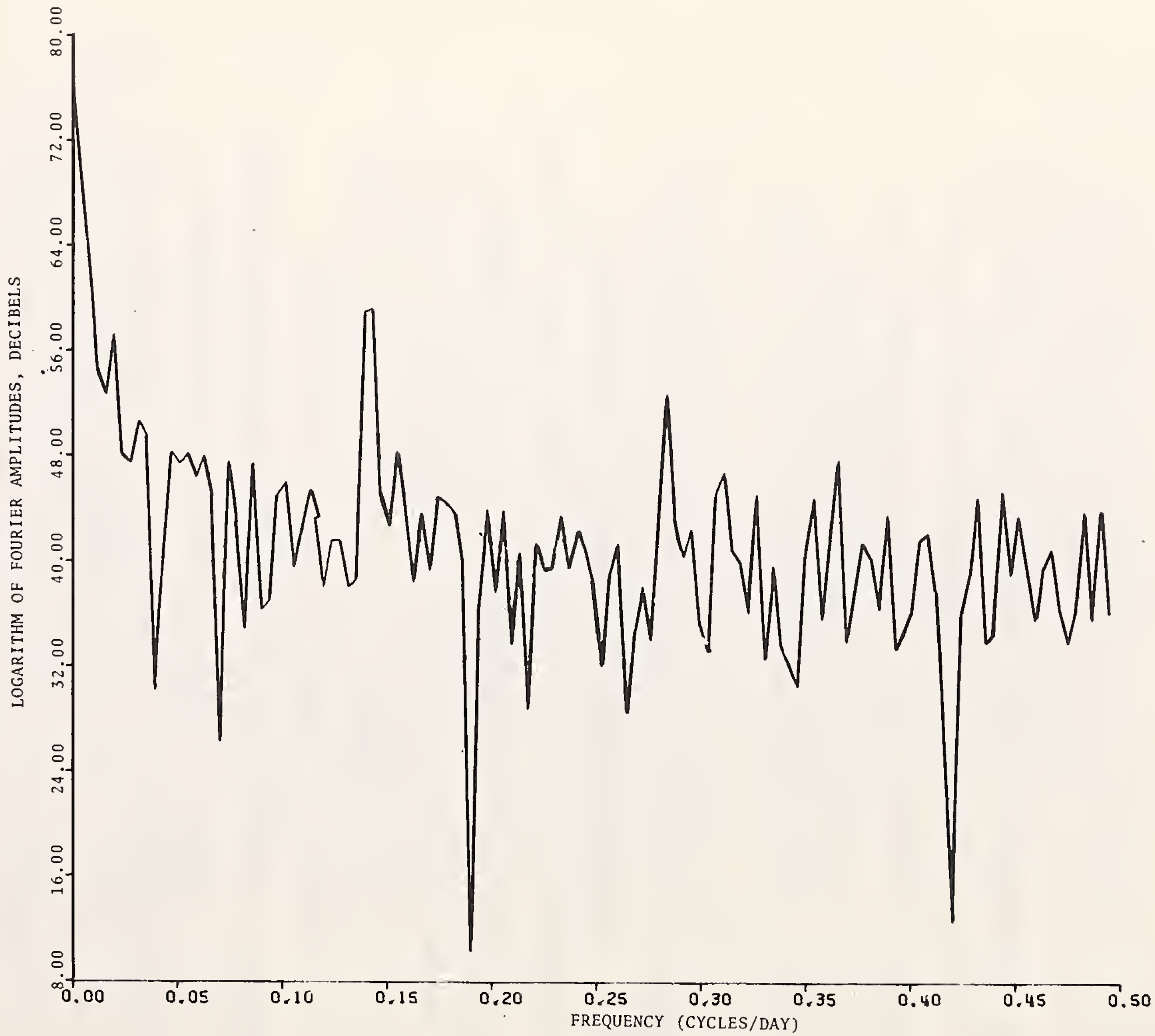

FIGURE 4-2. POWER SPECTRUM OF TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, FIRST SIX MONTHS, 1973, 4PM-10PM.

amplitudes prevented an accurate assessment of possible DST-related traffic fatalities.

Figures 4-3 through 4-6 are plots of weekly totals of raw fatality data obtained by the NHTSA from the States specifically for the current study. Total U.S. fatalities occurring each week at certain hours of the day for a specified time period are plotted as functions of week number. Thus, Figure 4-3 reflects total U.S. fatalities from traffic accidents occurring between 4 a.m. - 10 a.m. for each week from October 7, 1973 (i.e., October 7-13) through May 5, 1974 (i.e., May 5-11); Figure 4-4, same dates, 4 p.m. - 10 p.m. Figure 4-5 reflects the weeks extending from October 6, 1974, to May 4, 1975, and time of day 4 a.m. - 10 a.m.; Figure 4-6, same dates, 4 p.m. - 10 p.m. Each figure exhibits the same type of data variations as Figure 4-1, except that weekly instead of daily totals tend to smooth out some of these variations, thereby eliminating certain trends. These eliminated daily trends contain some DST-related fatalities, making the search for DST effects in this study even more difficult than in the earlier study.[1]

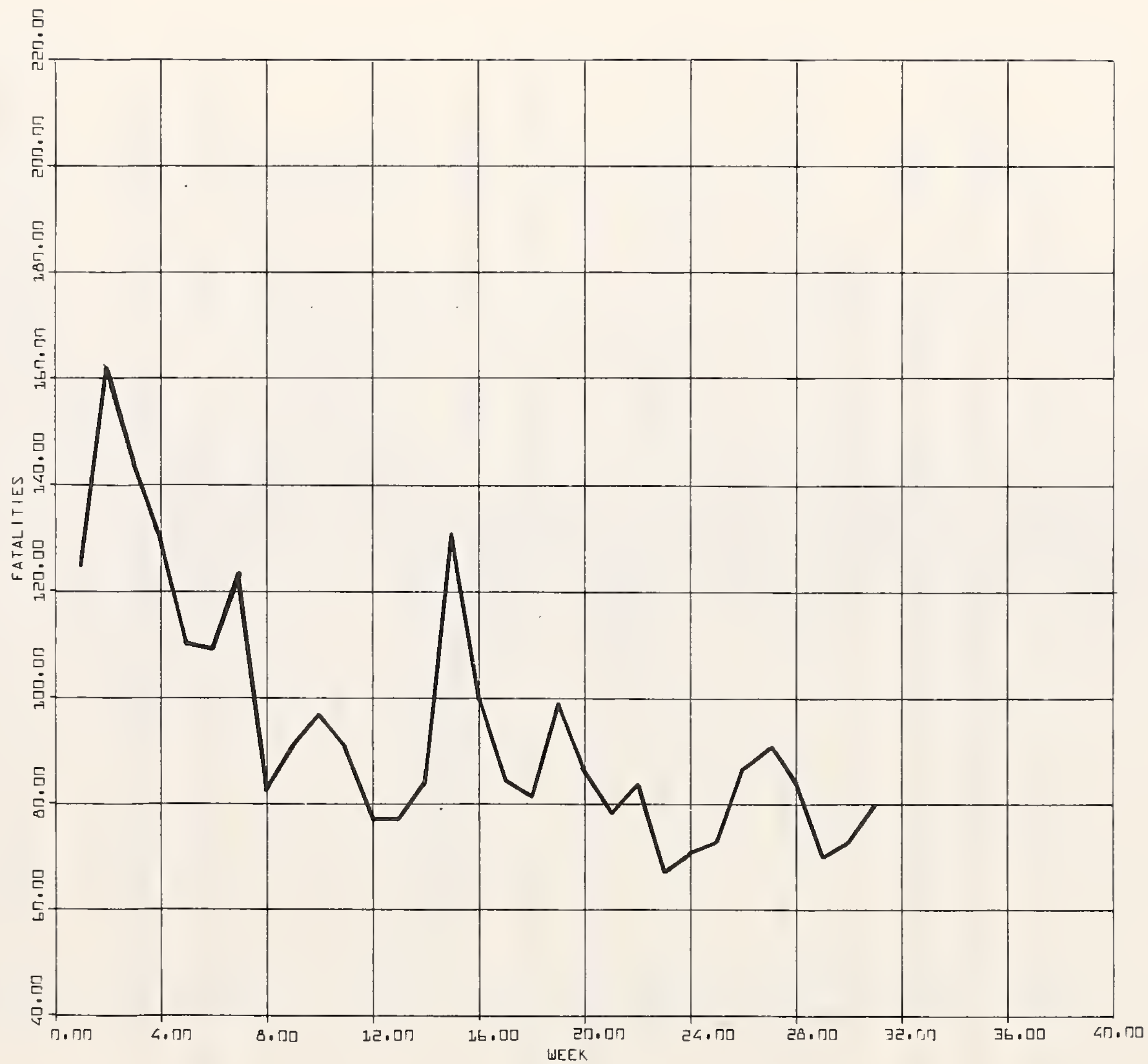

FIGURE 4-3. TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 7, 1973 - MAY 5, 1974, 4AM-10AM.

FIGURE 4-4. TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 7, 1973 - May 5, 1974, 4PM-10PM.

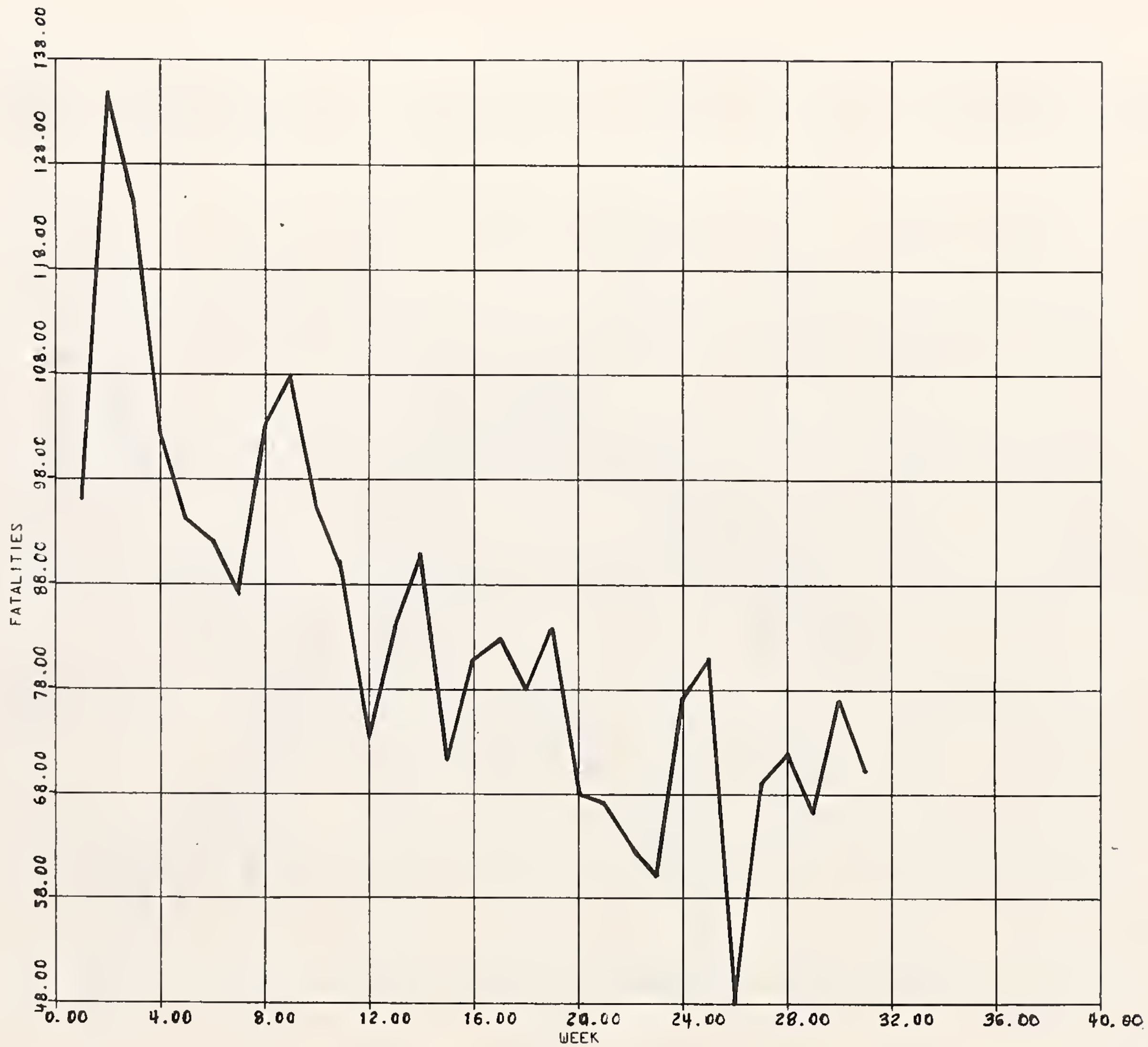

FIGURE 4-5. TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 6, 1974 - MAY 4, 1975, 4AM-10AM.

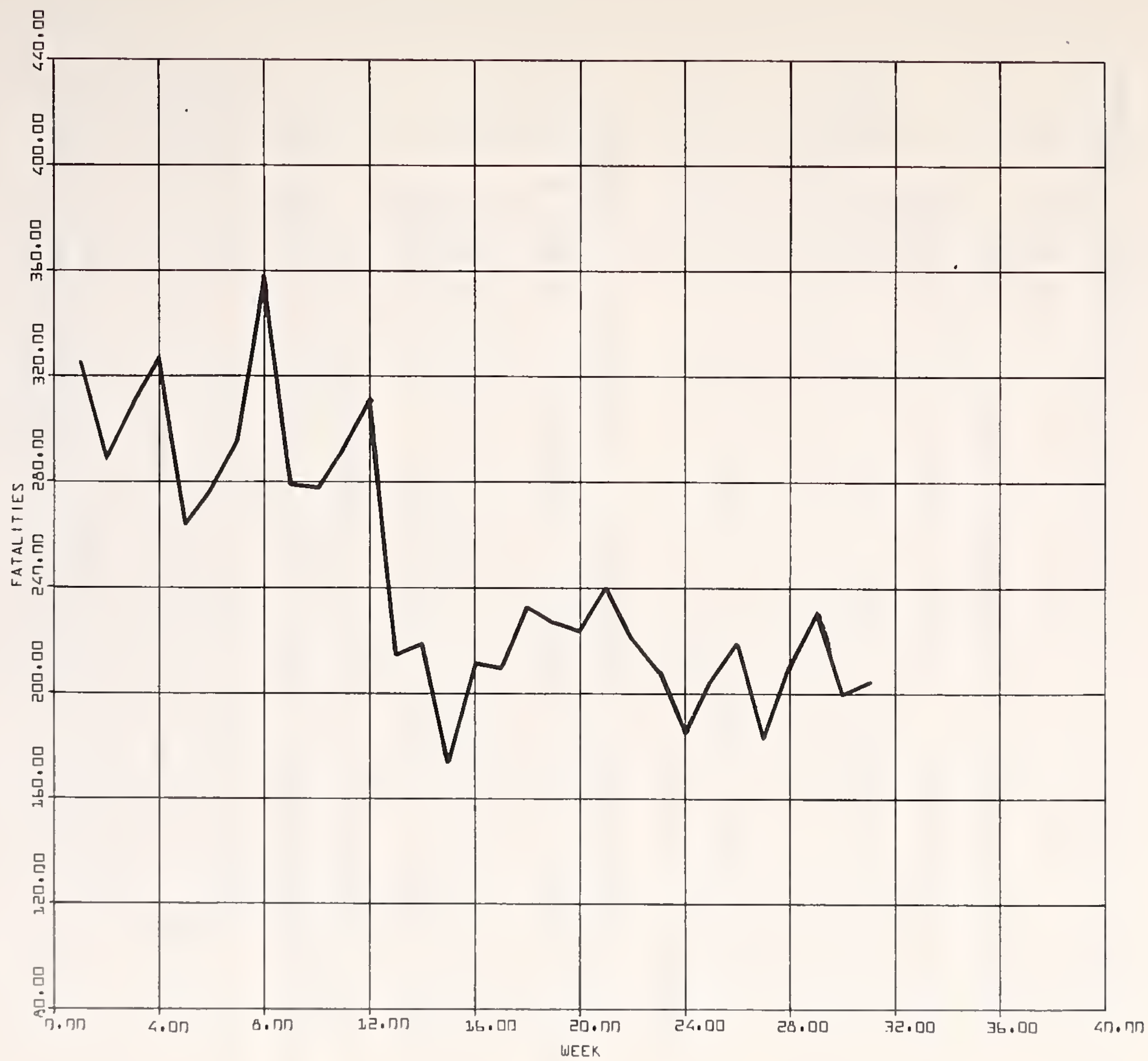

FIGURE 4-6. TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 6, 1974 - MAY 4, 1975, 4PM-10PM.

4.2 USE OF FOURIER SPECTRA TO IDENTIFY TRENDS IN TRAFFIC FATALITY DATA

Each individual trend, which reflects some specific aspect of fatal accidents, generates a characteristic frequency in the data. Fourier analysis can separate many of these frequencies from one another, thereby permitting spectral analysis of each. As indicated above, fatalities were sampled weekly and this tends to obscure the complete effect of DST on fatalities. Nevertheless, it is still possible to make a number of important observations.

Figure 4-7 is the Fourier transform of total U.S. weekly fatality data for the period October 7,1973-May 5,1974, 4 a.m.-10 a.m. There is a significant increase in the Fourier amplitude below about 0.03 CPW (cycle/week). The Fourier amplitude in the vicinity of 0 CPW is essentially the representation in frequency space of the long term trends in temporal space. Likewise, base level variations in signals (at frequencies greater than about 0.03 CPW) are representations in frequency space of shorter term trends in temporal space. The amplitude at 0 CPW is larger than the average base level signals by a factor of about 30 to 1. Physically, this means that the amplitudes of the short-term variations in (temporal) space are smaller than those of the long-term trends by a factor of around 30. Variations due to DST would therefore

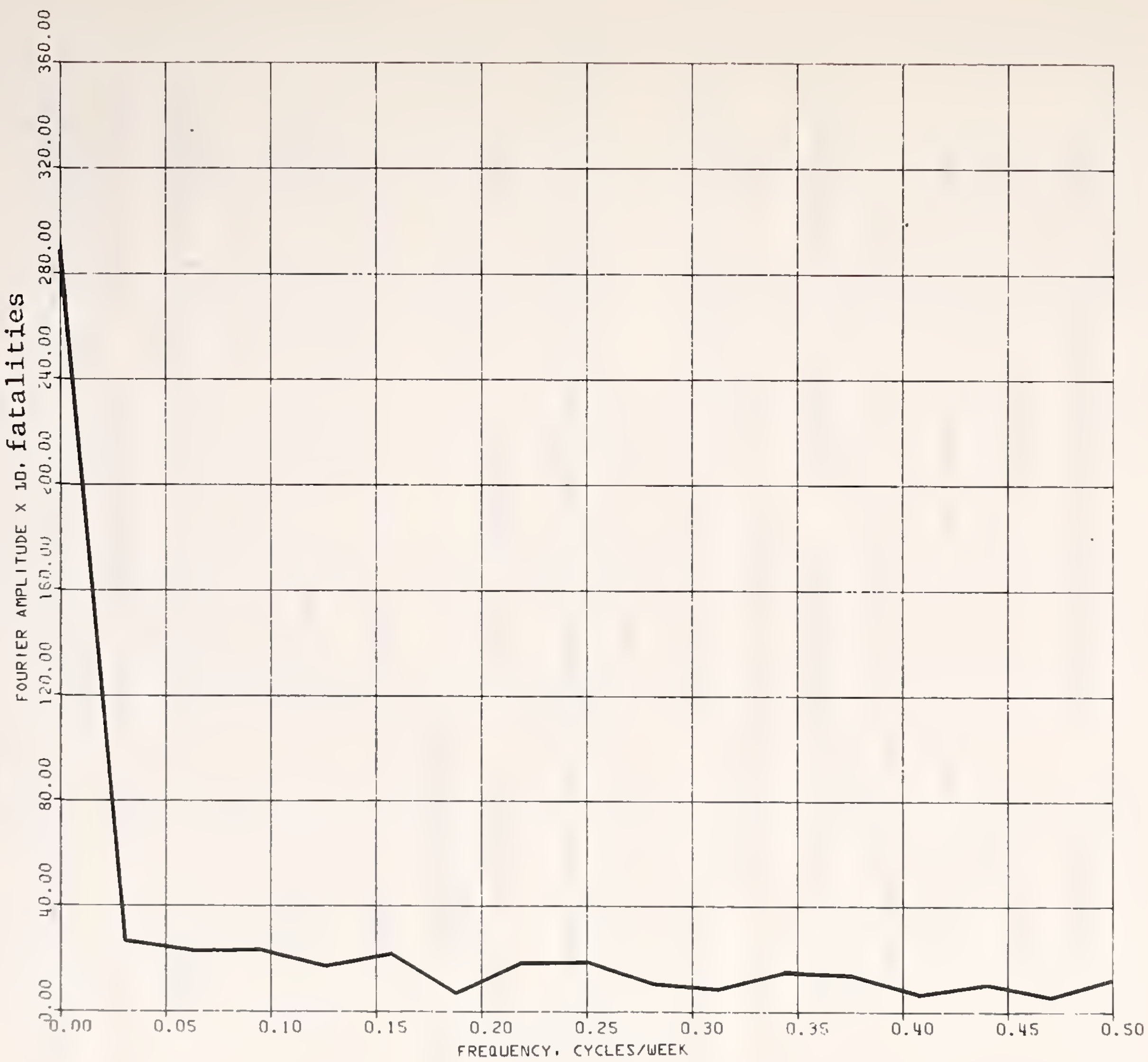

FIGURE 4-7. FOURIER TRANSFORM OF TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 7, 1973 - MAY 5, 1974, 4AM-10AM.

tend to be made obscure if Fourier amplitudes in the vicinity of 0.03 CPW or less were permitted to remain in the fatality data.

Figure 4-8 contains the same basic information as Figure 4-7 except that the vertical axis is now proportional to the logarithm of the Fourier amplitudes. The vertical scale is effectively compressed, so that variations in the Fourier amplitudes are more easily discernible. (Figure 4-8 does not exhibit the type of fine structure shown in Figure 4-2. As explained in Section 5, the absence of fine structure is to be expected because fatalities are sampled weekly.) Interpretations that can be derived from Figure 4-8 are therefore limited, although the low frequency cut off is more clearly defined than in Figure 4-7.

Figure 4-9 is the Fourier transform of nationwide weekly fatalities from October 7,1973 to May 5, 1974, 4 p.m.-10 p.m., and Figure 4-10 has a plot of the logarithms of the Fourier amplitudes. Figure 4-11 is the Fourier transform of fatalities from October 6,1974 to May 4,1975, 4 a.m.-10 a.m., while Figure 4-13 shows the corresponding Fourier transform for the evening hours, 4 p.m.-10 p.m. Figures 4-12 and 4-14 show the corresponding logarithmic variations.

It is informative to compare the differences between the maximum frequencies in Figures 4-7 to 4-14 and in Figure 4-2. Since 0.5 CPW = 0.07 CPD and the dominant trend in Figure 4-2

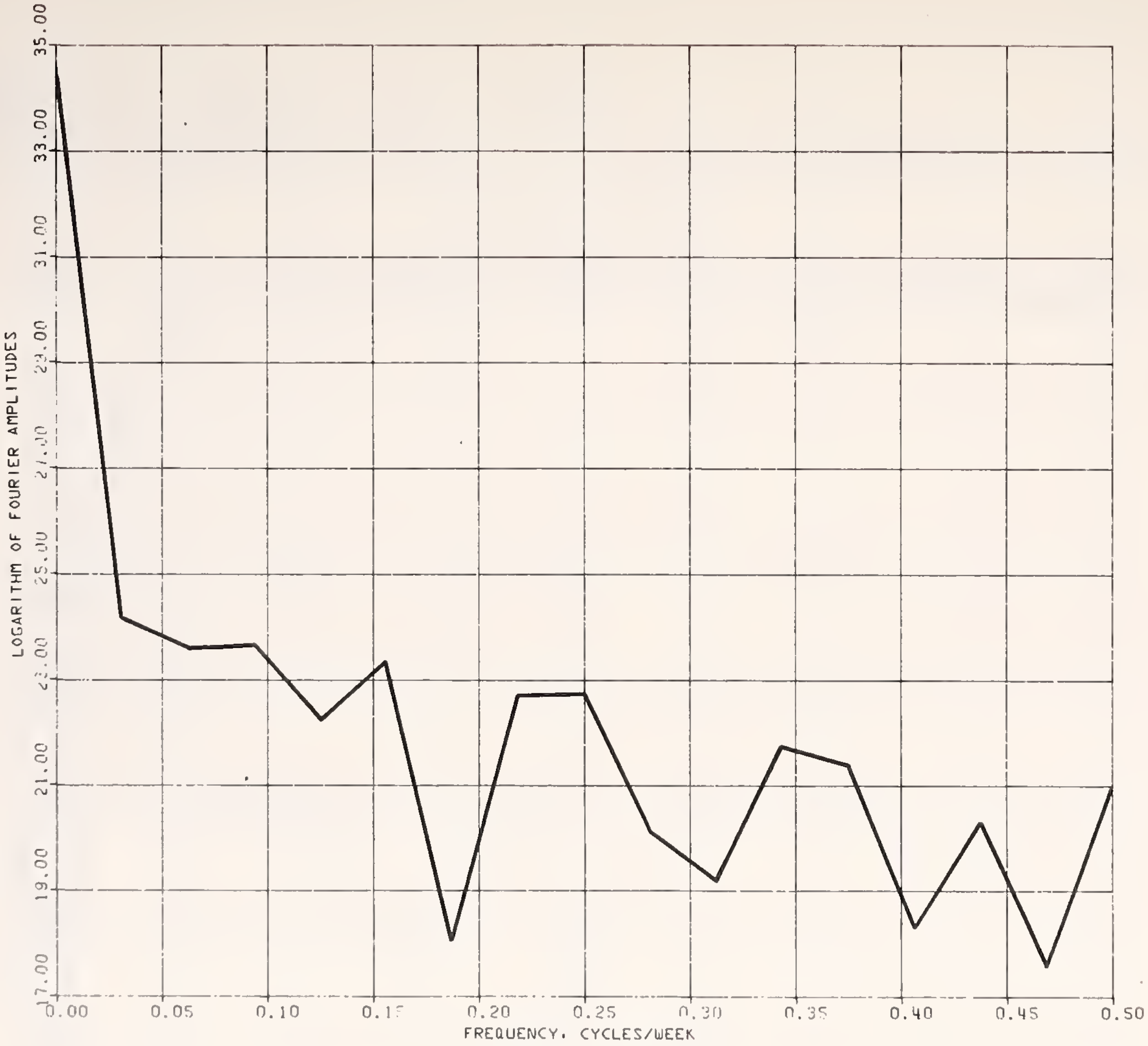

FIGURE 4-8. POWER SPECTRA OF TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 7, 1973 - MAY 5, 1974, 4AM-10AM.

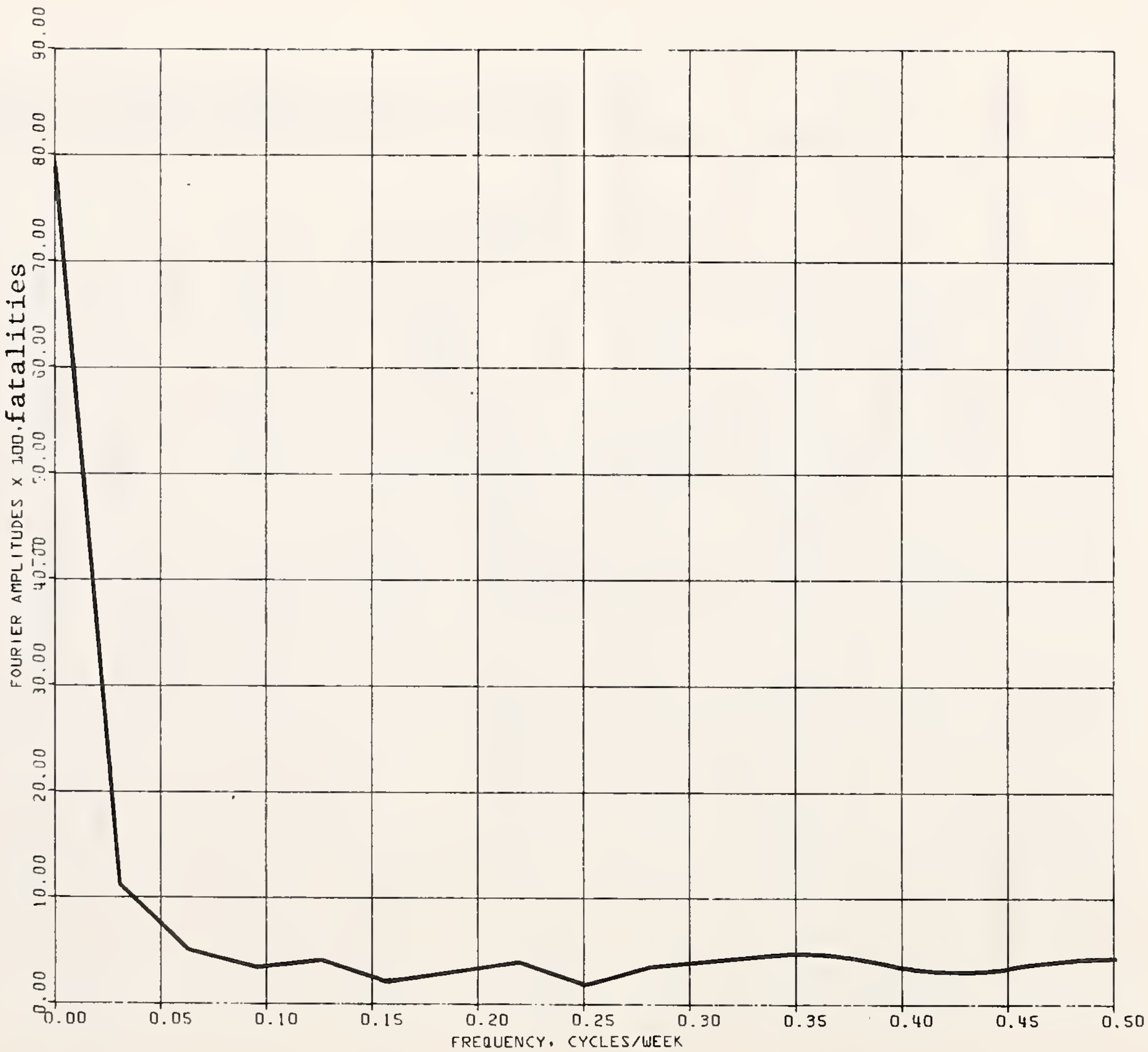

FIGURE 4-9. FOURIER TRANSFORM OF TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 7, 1973 - MAY 5, 1974, 4PM-10PM.

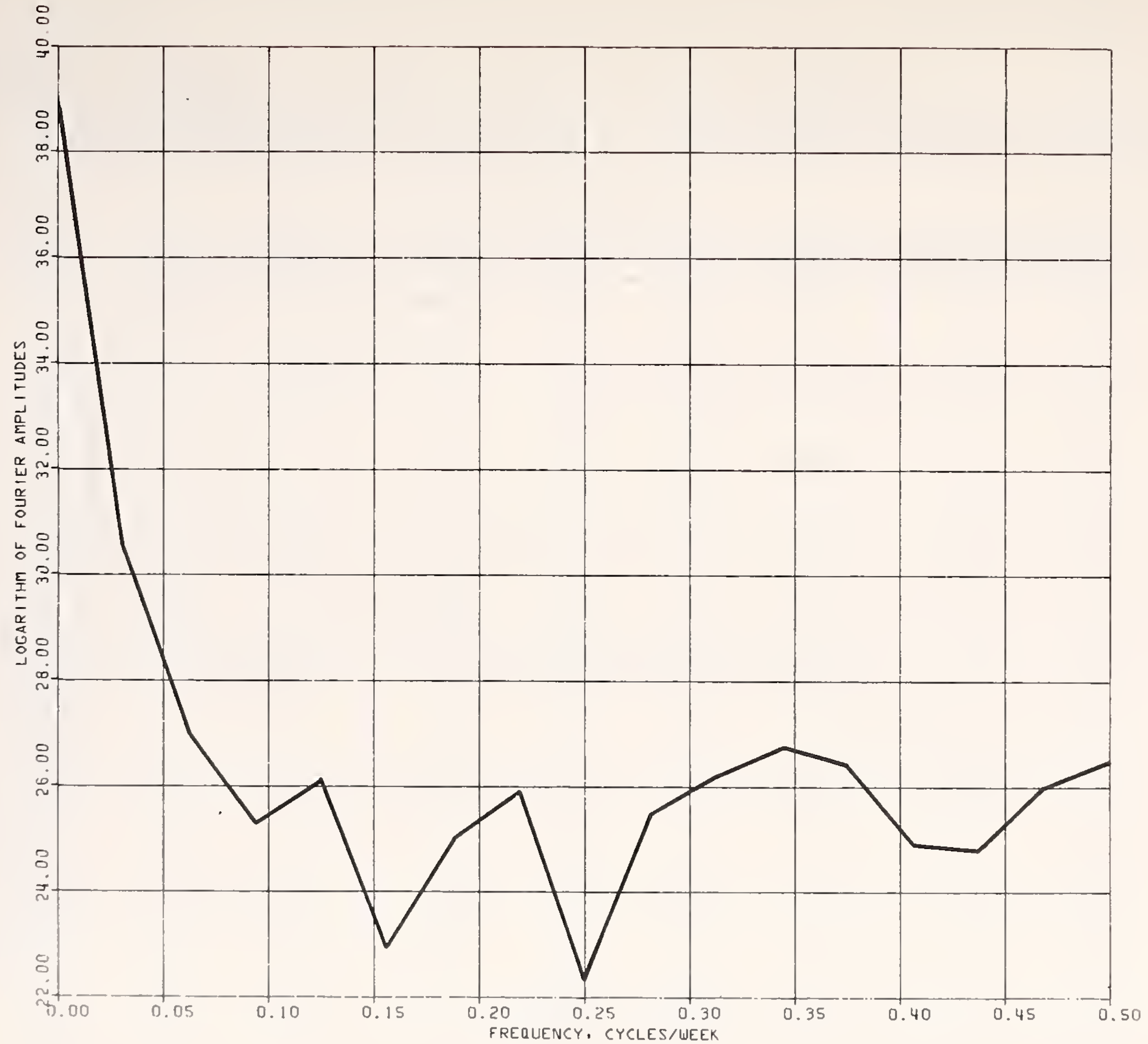

FIGURE 4-10. POWER SPECTRA OF TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 7, 1973 - MAY 5, 1974, 4PM-10PM.

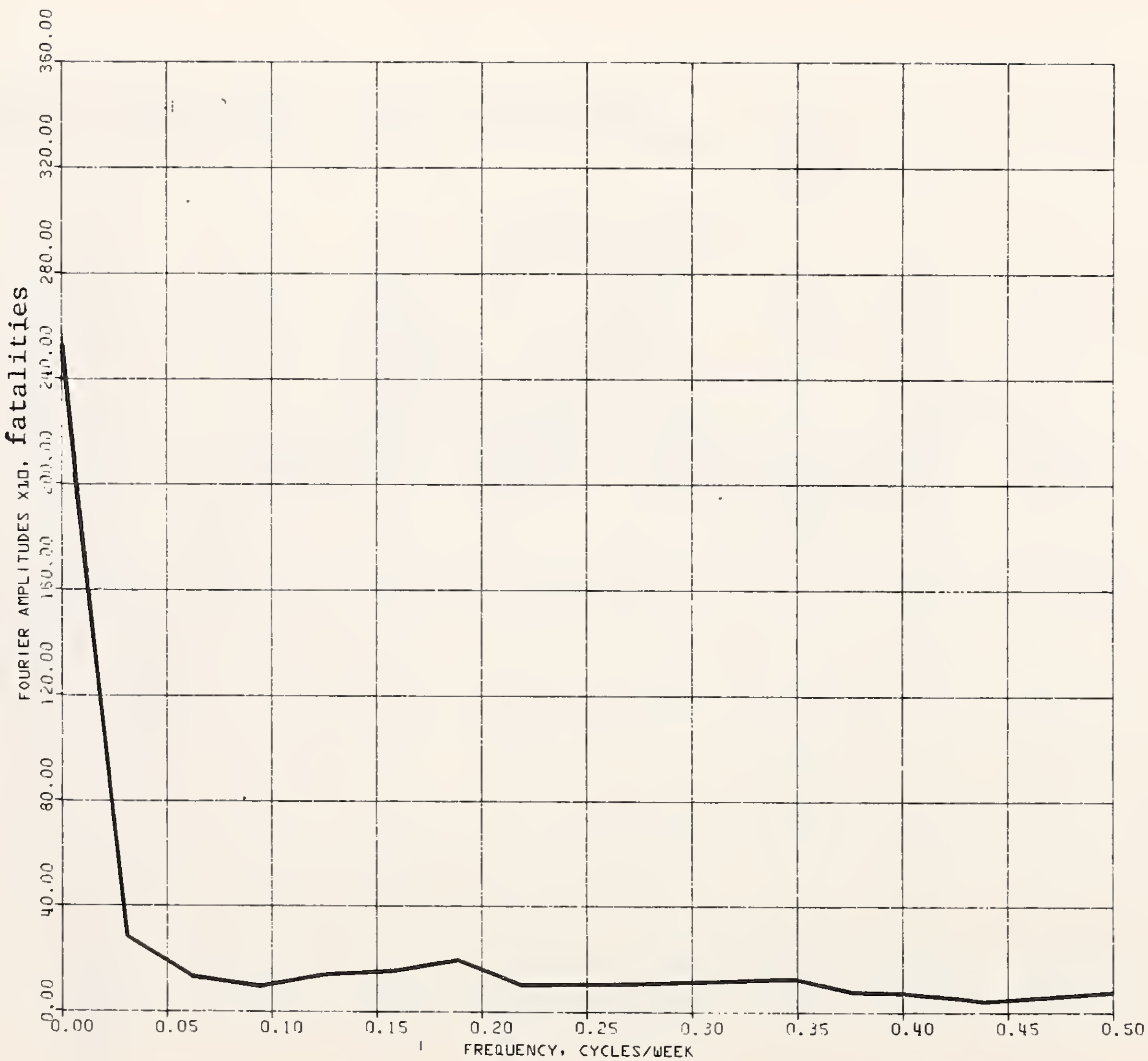

FIGURE 4-11. FOURIER TRANSFORM OF TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 6, 1974 - MAY 4, 1975, 4AM-10AM.

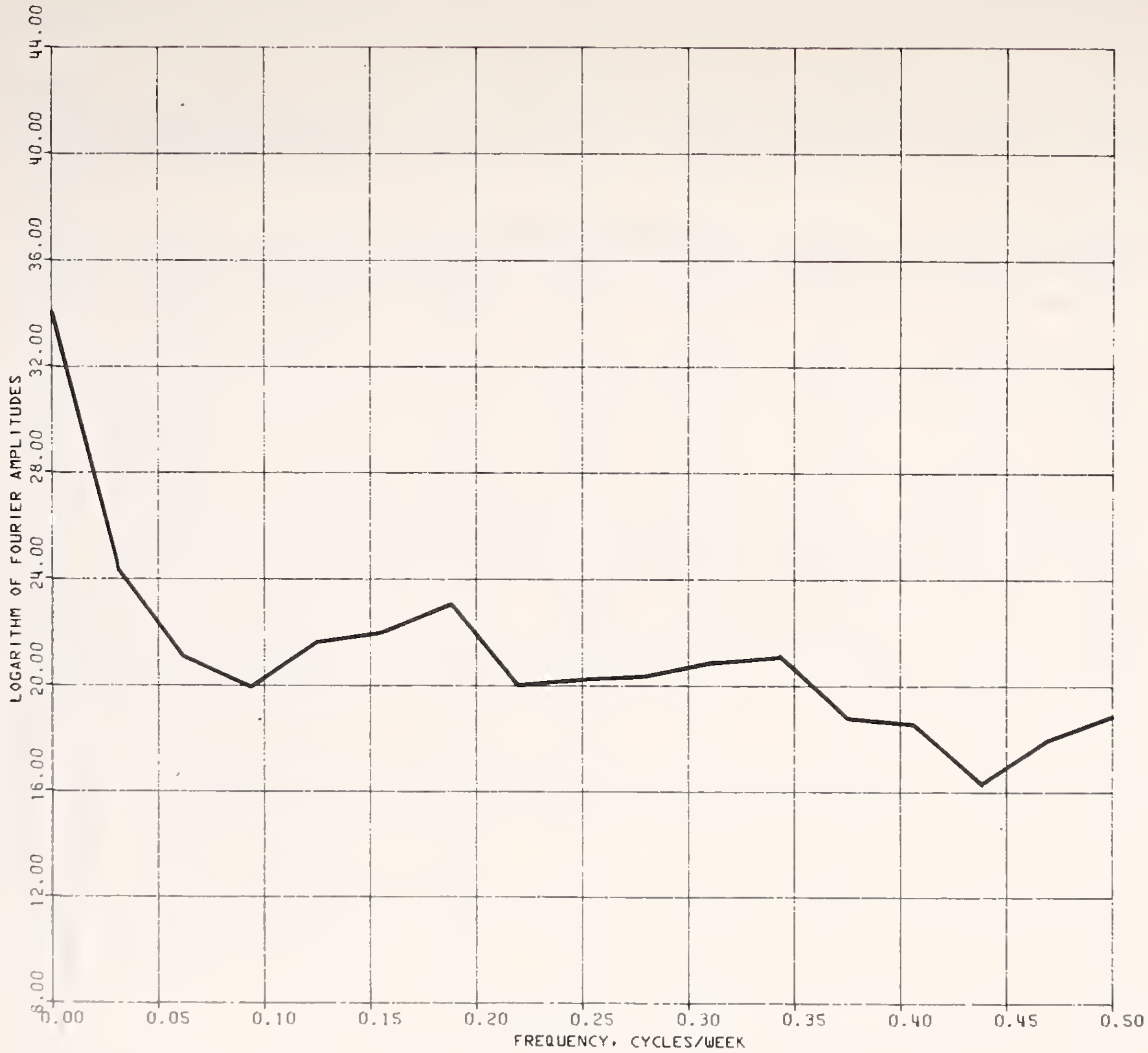

FIGURE 4-12. POWER SPECTRA OF TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 6, 1974 - MAY 4, 1975, 4AM-10AM.

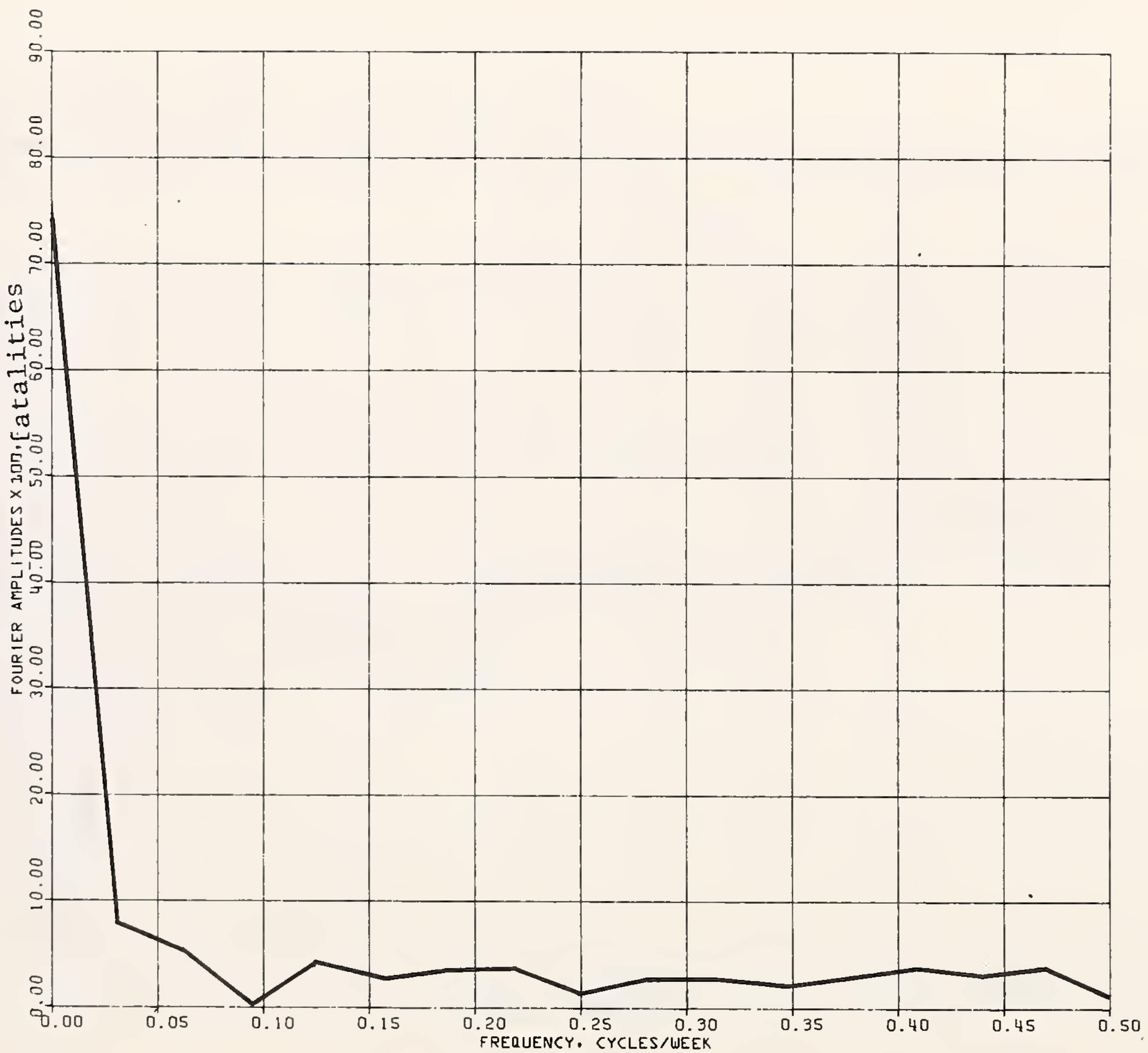

FIGURE 4-13. FOURIER TRANSFORM OF TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 6, 1974 - MAY 4, 1975, 4PM-10PM.

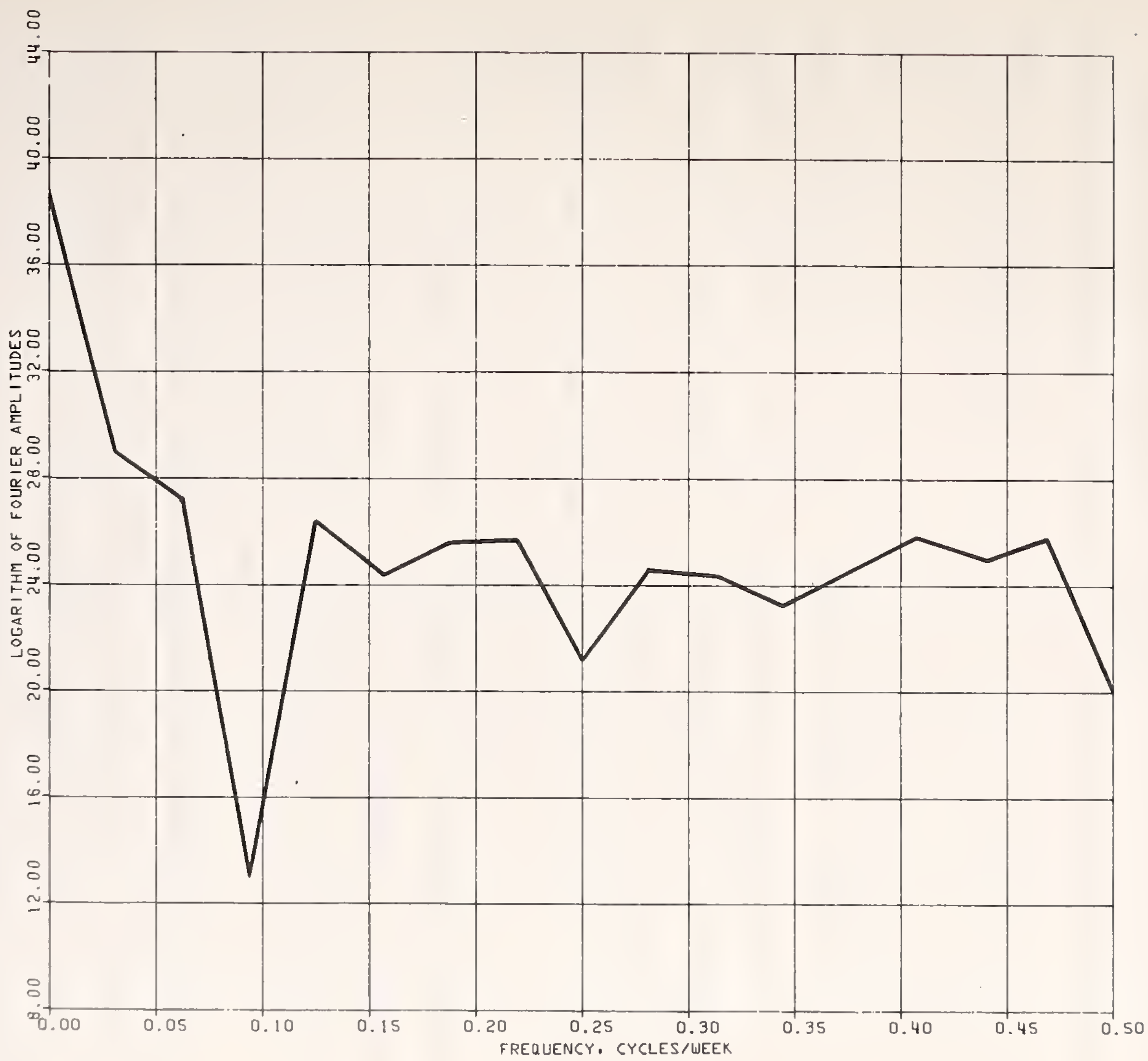

FIGURE 4-14. POWER SPECTRA OF TOTAL U.S. FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 6, 1974 - MAY 4, 1975, 4PM-10PM.

extends from roughly 0 to 0.3 CPD, the filtering to be described in the next section will be necessarily limited to removing only part of the long term trends.

5. MATHEMATICAL ANALYSIS OF TRAFFIC ACCIDENT FATALITIES

Earlier sections have alluded to the use of spectral analysis and digital filtering as ways of analyzing motor vehicle accident data. Although such procedures are being applied to the analysis of these data for what is probably the first time, some of the basic techniques involved have been used successfully in many diverse fields. Applications range from the analysis of extraterrestrial signals and radar reflections from aircraft to investigations of national finances. This section will demonstrate mathematically the application of these procedures to the analysis of motor vehicle traffic accidents by showing how:

(1) Fourier analysis is applied to traffic fatality data.

(2) Digital filtering is used to remove or suppress those fatality trends which are not associated with DST but only tend to obscure the effects of DST.

(3) DST-related fatalities can be measured by the combined usage of Fourier transformations and digital filtering.

In this section, it will also be shown that the best estimate of the minimum number of DST-related fatalities is made at high frequencies.

5.1 SELECTION OF TECHNIQUES FOR ANALYZING SMALL CHANGES IN THE DATA

To determine the impact of DST on traffic accidents, an appropriate method of (time series) analysis must be able not only to distinguish between a small effect and a large one but to estimate the magnitude of the small effect as well. This requirement eliminates virtually all conventional time series methods that would normally be used to determine general trends in accident data because, in using these procedures, "noise" (i.e., small variations) in the data is usually eliminated or made obscure and, unfortunately, DST-related accidents are part of the noise and cannot be eliminated. For example, the simplest method of analyzing variations in accident frequency due to DST would be to add together samples of accident data before and after a transition, or from one year to the next, and compare results. But this only serves to further identify non DST-related trends since the variance of (uncorrelated) noise in the data trends to increase. Thus, if DST-related accidents are indeed part of the noise, then adding together accident samples would only obscure their presence.

In view of the foregoing considerations, the usual methods of time series analysis may safely be ruled out. These procedures include simple averaging (as already indicated), standard least square curve fitting techniques, and many other

methods which are summarized in reference 3. Application of standard statistical tests such as parametric analysis are also ruled out because inclusion of the trend would only serve to diminish the sensitivity of the tests, since it is mostly the trend that would be tested rather than the (DST) noise. By way of analogy, a six inch scale would be used to measure the length of an object if it were known that its length is between one and six inches, whereas a yard stick would be inappropriate. Likewise, any technique which would measure only the broad, general trends in accidents, and not the small variations in these trends, would be inappropriate for assessing the effects of DST on accidents.

It has been pointed out above that it is not easy to perform a time series analysis of traffic fatality data which includes the requirement to measure small variations in the data as well. The next step is to ascertain if it is at all possible to analyze these fatality time series for frequency content since the frequencies involved are not mathematical artifices but, instead, are manifestations of natural accident phenomena in the form of accident trends of varying temporal extent. With this approach, frequency bands containing signals of relatively large amplitudes which are known to be unrelated to DST can be identified by a mathematical method known as the Fourier transformation of data, and subsequently removed by another method known as digital filtering. These frequency bands

are the manifestation in frequency space of the broad, general trends of traffic fatalities in temporal space, and are identifiable by their low frequency content. On the other hand, frequency bands reflecting DST-related fatalities are identifiable by their high frequency content (as will be shown later in this chapter).

Figure 5-1 is a schematic diagram illustrating the overall approach to data analysis used in this study. The next two sections will explain the application of Fourier transforms and digital filtering in greater detail.

5.2 FOURIER ANALYSIS OF FATALITY TIME SERIES

The Fourier integral is essentially defined as[4]

$$F(w) = \int_{0}^{T} S(t)\exp(iwt)\,dt, \qquad (5\text{-}1)$$

aside from some unimportant numerical factors. Exp is an abbreviation for exponentiation of iwt with respect to the base e (= 2.718) of natural logarithms. $S(t)$ represents the time series of raw fatality data, w is the frequency in radians per unit time, $i=(-1)^{1/2}$, and $F(w)$ is the Fourier transform of

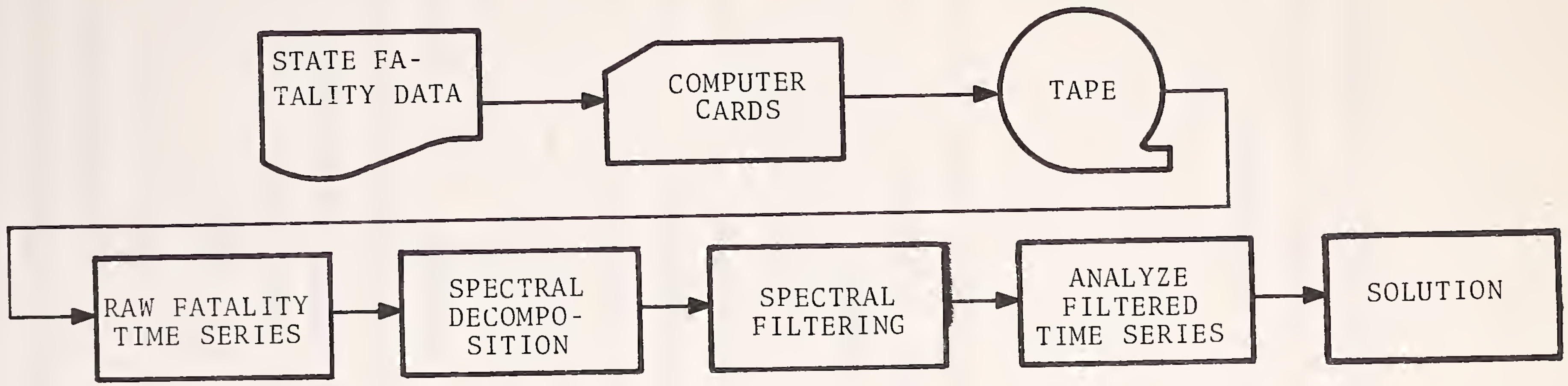

FIGURE 5-1. SELECTIVE REMOVAL OF LOW FREQUENCIES ASSOCIATED WITH NON-DST RELATED TRENDS FROM U.S. MOTOR VEHICLE TRAFFIC ACCIDENT FATALITY DATA.

S(t),i.e., the representation of S(t) in frequency space. The integration is performed over the data for a time duration T . The circular frequency w may be expressed as

$$w = 2\pi f \tag{5-2a}$$

$$f = 1/T \tag{5-2b}$$

where f is the frequency in units of 1/time. The essence of Fourier analysis is that a plot of $|F(w)|$ vs. w(or f) will show the relative frequency distribution contained in S(t). That is, the fatality time series S(t) is represented mathematically by a superposition of waves, each possessing a unique frequency f, and hence a unique periodicity T. Each wave will also have an amplitude which is generally unique. (Frequency is the number of cycles per unit of time that each wave repeats itself, periodicity is the time of the repetition, and amplitude is the strength or magnitude of the changes. For example, if on Mondays about 20 fatalities usually occur, then the periodicity of the wave representing Monday fatalities is 7 days, the frequency is 1/7 = 0.14 cycle/day and the amplitude is 20 fatalities.) As indicated in Section 4, these waves (or trends) are physical. Fourier analysis is simply a convenient mathematical tool for showing how each of these waves varies in the frequency domain. As applied to fatalities, different trends in the general fatality population will quite often

have different frequency and amplitude components in the frequency domain, thus permitting them to be distinguished from one another. Visual examination can identify components not pertinent to the analysis. These can therefore be filtered or separated out more easily in frequency space than in temporal space. (Section 5.3 following shows how this filtering is done.)

Representing motor vehicle accident phenomena as a superposition of waves with varying frequencies and amplitudes may seem unusual, but it should be remembered that many different types of physical phenomena have been represented by waves for over one hundred years. Two examples are the electromagnetic theory of light and the theory of vibrations of structures (buildings, bridges, aircraft wings, etc.) In retrospect, the application of this concept to accidents is a very simple and natural one, because some of these wave representations are actually seen in the raw fatality data (see weekly variations in Figure 4-1).

The principal limitation to the application of the Fourier transform is that data samples must be equally spaced in time, otherwise spurious frequencies will appear in the frequency spectrum. In practice, however, this is not a serious problem because it is usually possible to group data samples so that they are spaced equally.

The computational technique for obtaining the Fourier transform of fatality data is based on the well-known method of

Cooley and Tukey[5], which is a relatively modern development. In the technical literature it is sometimes referred to as the Cooley-Tukey FFT (Fast Fourier Transform). With this method, computer time required to calculate the transform has been reduced to being roughly proportional to N(log N), where N is the number of data samples in the time series. Prior to development of the FFT, the conventional computational technique for obtaining the Fourier transform required an amount of computer time proportional to $(N)^2$. For large N, an exhorbitant amount of computer time was required, (e.g., doubling the number of samples would increase the running time fourfold). This may be one reason why the Fourier transform, although developed in the nineteenth century, has only recently become popular as an analytical tool. In fact, the techniques developed for this particular study of traffic fatalities may have significant potential for analyzing other types of accident data, although, in the present instance, they are applied only to a very special (and relatively difficult) problem.

5.3 THE FATALITY FILTER

The function of this filter[6] is to suppress undesired fatality frequencies, but to leave undisturbed the desired frequencies. (In normal operation, the filter is designed to accept any two frequencies at a time. It will suppress all frequencies smaller than the lower, or larger than the upper frequency. For example, if the filter is assigned the frequencies 1 CPW (Cycle/Week) and 2 CPW, it will suppress all frequencies less than 1 or greater than 2 CPW. All frequencies between 1 and 2 CPW in the time series will remain unaffected. Filters with these operational characteristics are customarily referred to as "bandpass" filters.)

The filter will not distort the time series when it accepts or rejects specified frequency bands. Thus, there is no phase loss in the signal and the gain of the filter is unity. By way of clarification, these "phase" and "gain" properties of the filter describe how efficiently the filter leaves undisturbed those fatality waves that are permitted to pass through it. In particular, "no phase loss" means that all waves emerging from the filter have the same relative spacing as before entering the filter. For instance, that part of the wave representing Tuesday would always precede by precisely one day the Wednesday part of the wave. "Gain" is the number of fatalities in the

output wave divided by the number of input fatalities. If, for example, each Tuesday wave had 30 fatalities before and after filtering, the gain of the filter would by unity. These attributes of the "phase" and "gain" properties of the filter are of course just what common sense would require. However, many filters, for one reason or another, do not have these attributes.

The particular bandpass filter used in this analysis is a relatively simple one which was general enough in design to be applicable to motor vehicle accidents. It would have been possible to design a filter specifically suited to the special characteristics of the DST hypothesis (such filters are usually called "matching filters") were it not for time constraints. It is encouraging that application of this filter does lead to measurable effects of DST on fatalities. It is believed that the penalty for not using a more specialized filter design has been to slightly underestimate the magnitude of these effects.

The basic technique in applying the filter is to multiply the Fourier transform of the fatality time series by a mathematical function which is essentially the filter response, and then to take the inverse transform of this product, in order to restore the original time series, minus the frequency components that have been filtered out. The filter response is essentially a specially constructed weighting function that

suppresses only those frequency regions that are specified. The mathematics are presented below.

The most general form of the Fourier integral of the fatality time series S(t) is given by Eq. (5-1) in Section 5.2. Its inverse transform is

$$S(t) = \int_{-\infty}^{\infty} F(w)\exp(-iwt)\,dw \tag{5-3}$$

Now define a convolution integral:

$$S(t') = \int_{-\infty}^{\infty} G(t)\,S_i(t-t')\,dt \tag{5-4}$$

where it is assumed that G and $S_i(t-t')$ are not singular, i.e., there are no t's for which G and S_i become infinite (this requirement is easily satisfied by fatality data). Physically, $S_i(t-t')$ is the input to the filter and $S_o(t')$ is its output. G is a function of the filter that operates on $S_i(t-t')$ in order to transform it to $S_o(t')$. Substituting Equation (5-3) into Equation (5-4) gives:

$$S_o(t') = \int_{-\infty}^{\infty} G(t)\,dt \int_{-\infty}^{\infty} \exp[-iw(t-t')]S(w)\,dw$$

$$= \int_{-\infty}^{\infty} G(t)\exp(-iwt)\,dt \int_{-\infty}^{\infty} S(w)\exp(iwt')\,dw$$

$$= \int_{-\infty}^{\infty} G(w)\, S(w) \exp(iwt')\, dw \qquad (5\text{-}5)$$

Dropping primes and subscripts,

$$S(t) = \int_{-\infty}^{\infty} G(w)\, S(w) \exp(iwt)\, dw \qquad (5\text{-}6)$$

Once G(w) is specified, its transform is computed by an equation of the type (5-3). Then G(t) is substituted into Equation (5-4) to reconstruct the filtered fatality time series, S(t).

Filtered data are fluctuations in fatalities about that part of the data (usually trends) that has been suppressed. This interpretation implies that filtered data can be negative, as well as positive. For instance, suppose the bandwidth is 0-0.5 CPW. If frequencies in the range 0-0.2 CPW are suppressed and the number of fatalities are -21, the interpretation is that there are 21 fatalities less in the frequency range 0.2-0.5 than there are in the range 0-0.2.

The shape of G(w), the filter response, is given in Figure 5-2. It has two important properties: (1) The gain is unity which ensures that the amplitude of the filtered signal will remain unchanged. (2) The filter is designed so that it will only accept frequencies in the specified range w1 to w4 and suppress frequencies outside this range. The differences w2-w1 and w4-w3 are adjustable, thereby enabling the filter roll-off

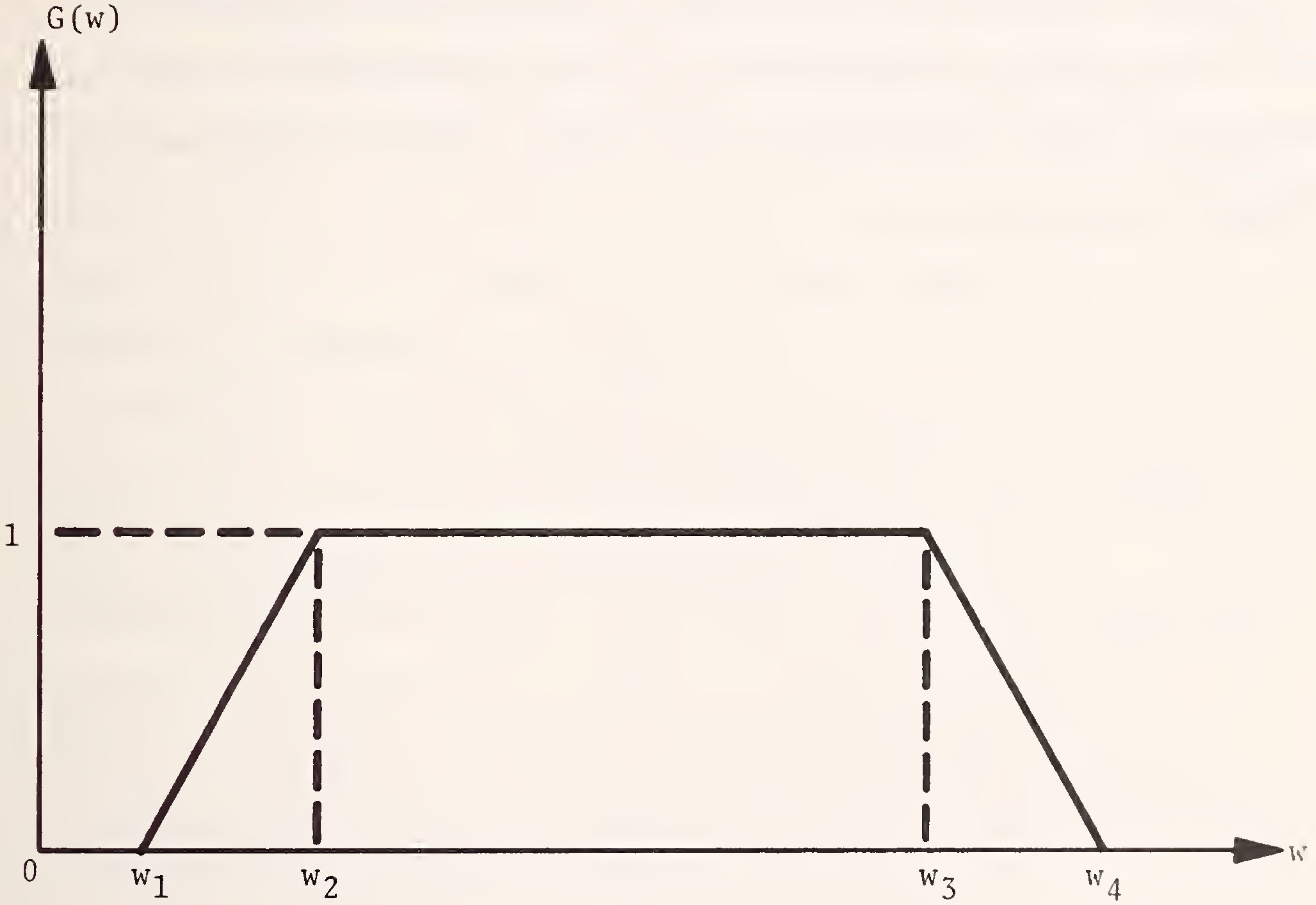

FIGURE 5-2. FILTER RESPONSE IN FREQUENCY SPACE $(w=2\pi f)$

or change in G(W) to be made fairly sharp, if desired. A sharp roll-off will suppress frequencies that are in close proximity to selected frequencies.

Whereas w2 and w3 are specified, w1 and w4 are computed automatically and are consistent with the requirements of the Nyquist principle and frequency resolution criteria stated in Section 5.6.

5.4 PERTURBATIONS IN THE FOURIER SPECTRUM

This section will develop a representative case to show how changes in fatalities related to DST affect the Fourier spectrum. The example applies (with some minor modifications) either to transition analyses or year-to-year comparisons (see Section 6), but for pedagogical purposes, assume that only a transition analysis is involved.

Figure 5-3 shows a simplified representation of traffic fatalities as a function of time (measured in any convenient unit: hours, days, etc.) At time $T'/2$ (chosen for mathematical convenience) a transition is made to or from DST, causing a change ΔN in the number of fatalities. ΔN can either be postive or negative, depending upon the type of transition and the time of day. The Fourier transform of the traffic fatality time series is

$$F(w) = \int_{0}^{T'} N\exp(-iwt)\,dt + \int_{T'/2}^{T'} (\Delta N)\exp(-iwt)\,dt \qquad (5-7)$$

After integrating and grouping corresponding terms, the result is

$$F(w) = [(N+\Delta N)/w]\sin(wT') - (\Delta N/w)\sin(wT'/2)$$

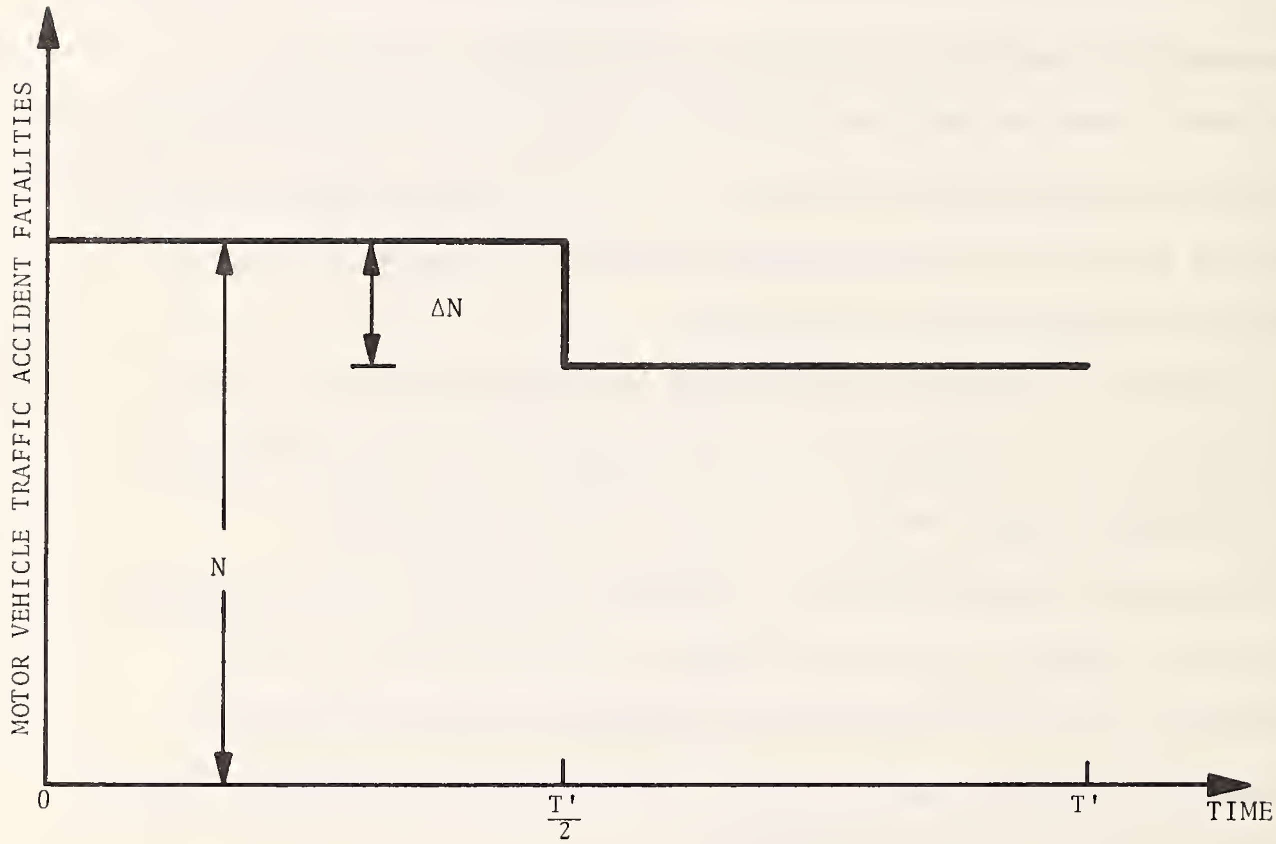

FIGURE 5-3. DAYLIGHT SAVING TIME CAUSES A CHANGE ΔN IN THE NUMBER OF FATALITIES N ($\Delta N \lesssim 0$).

$$+ i\{[N + \Delta N)/w]\cos(wT') - [N/w + (\Delta N/w) \cos(wT'/2)]\}$$

The absolute value of F(w) is determined by

$$|F(w)|^2 = (4N^2/w^2) \sin^2(wT'/2) + \{[2N(\Delta N)/w^2]\sin^2(wT'/2)$$

$$+ [4N(\Delta N)/w^2 + 4(\Delta N/w)^2]\sin^2(wT'/4)\} \qquad (5\text{-}8)$$

The term in brackets { } is due only to the pulse of amplitude ΔN. It generates the frequencies $4\pi m/T'$ where $m = 0,1,2,3,\ldots.$ The first term is the classical expression for the Fourier transform of a square pulse[7], with frequencies given by $2\pi n/T'$, where $n = 0,1,2,3,\ldots$

5.5 SENSITIVITY ANALYSIS FOR THE FOURIER SPECTRUM

Section 5.4 showed how the Fourier spectrum is changed by DST. This section will specify the best part of the spectrum for measuring changes in fatalities.

Let ΔN be replaced by $\Delta N+E$, where E is an error term (all physical systems contain intrinsic errors, biases or inaccuracies). The expression for $|F(w)|$ becomes

$$
\begin{aligned}
|F(w)| = \{&-[2N^2/w^2 + (2N/w^2)(\Delta N + E)] \cos (wT') \\
&- (4N/w^2)(\Delta N + E)(1 + (\Delta N+E)/N)\cos(wT'/2) \\
&+ 2(N/w)^2 + 2(N/w^2)(\Delta N + E) \\
&+ (4N/w^2)(\Delta N + E)(1+(\Delta N+E)/N)\}^{\frac{1}{2}} \qquad (5\text{-}9)
\end{aligned}
$$

The partial derivative of $|F|$ is

$$d|F|/dE = U/V$$

where

$$U = (2N/w^2)\cos (wT') - [(8/w^2)\ \Delta N + 4N/w^2 + (8E/w^2)]\ \cos(wT'/2)$$

$$+ 6N/w^2 + 8\Delta N/w^2 + 8E/w^2 \tag{5-10}$$

$$V = 2\{-[(2N/w^2) + (2N/w^2)(\Delta N + E)]\cos(wT')$$

$$- (4N/w^2)[2\Delta N + 2E\Delta N/N + E^2/N + E + \Delta N + (\Delta N)^2]\cos(wT'/2)$$

$$+ 2(N/w)^2 + (2N/w^2)(\Delta N + E)$$

$$+ (4N/w^2)[\Delta N + ((\Delta N)^2 + E\Delta N)/N + E + (E\Delta N + E^2)/N]\}^{\frac{1}{2}} \tag{5-11}$$

It can be easily verfied that, in the limit, as w approaches infinity, $d|F|/dE$ approaches 0; conversely, as w approaches 0, $d|F|/dE$ approaches infinity.

The conclusion is that small variations in E at low frequencies will cause large variations in F, but at large frequencies, small variations in E have a lesser effect on F. It is therefore preferable to measure changes in traffic fatalities at higher frequencies (and filter out the low frequencies).

In summary, there are two reasons to take these measurements at high frequencies: (1) Large low frequency variations will obscure small DST-related effects, and (2) The Fourier spectrum (and therefore the filtered time series) is

less sensitive to inaccuracies. Even if every traffic fatality in the U.S. were in the fatality time series, it still would not be possible to measure very accurately those fatalities related to DST unless the measurements were at high frequencies. A more comprehensive sensitivity analysis would be needed in order to specify quantitatively what should be the delineation between "high" and "low" frequencies. However, the initial study (for the Congressional Report) of the effects of DST on traffic accidents[1] does make a reasonable judgement in this regard.

This example, i.e., introducing the error term E, is somewhat idealistic because N and ΔN are really functions of frequency and not constant as was assumed here. Nevertheless, the basic ideas remain unchanged.

5.6 ASSESSMENT OF DATA CHARACTERISTICS IN FATALITY TIME SERIES

The purpose of this assessment is to identify basic variables in the (transformed) data that are important to the analysis and to determine if the numerical values of these variables are likely to impose serious limitations on the accuracy of the analysis. It is important to perform this type of assessment prior to any application that involves analysis of a large data base.

There are two basic variables: the maximum frequency and the frequency resolution. Each will now be described in sections 5.6.1 and 5.6.2, respectively. Section 5.6.3 summarizes the assessment.

5.6.1 Maximum Frequency

The maximum frequency in the Fourier spectrum of traffic fatalities is estimated as follows. Because DST transitions change time by one hour, the change will generate a maximum frequency on the order of 1 cycle/hour (CPH). There are about 10 DST hours in each day, so that 1CPH=10 CPD =70 CPW. (If weekends are omitted the maximum frequency will be about 50 CPW).

Unfortunately, the method of data acquisition often removes the maximum possible frequency from the data. There is a theorem called the Nyquist sampling theorem[5] which in effect states that the sampling interval in the data determines a cut-off frequency that is equal to or lower than the maximum physically realizable frequency. The cut-off frequency (sometimes called the Nyquist frequency) is determined by the equation

$$f = 1/(2 \Delta t)$$

where f is the Nyquist frequency and Δt is the sampling interval. If accident data are summarized hourly, then $f = 0.5$ CPH =5CPD. If they are summarized weekly, then $f = 0.5$ CPW, which is the Nyquist frequency for this study.

In general, high frequency content imparts detail to the data. Because the number of DST-related fatalities is small, the degreee of detail is important. (The requirement that most data require high frequencies for adequate detail is well-established. For example, sometimes a photograph of a face may not show any wrinkles because high frequency components in the picture are absent.)

5.6.2 Frequency Resolution

The frequency resolution is a measure of how well adjacent frequencies in the Fourier spectrum are distinguished from each other. Estimates of the effects of DST on traffic fatalities become more accurate as the resolution between adjacent frequencies increases. Inaccuracies in frequency resolution are equivalent to inaccuracies in estimating the periodicity of trends in temporal space, for (mathematically) time and frequency are dual spaces.

An estimate of the frequency resolution is based on the length of the (fatality) time series.[8] The seasonal nature of motor vehicle accidents implies a base periodicity of about T=360 days. Hence 0.003 CPD is the frequency resolution for traffic fatality time series on an annual basis. This resolution is needed to properly identify short term trends or variations. On the other hand, the traffic fatality data used for this study have a temporal length equal to 31 (contiguous) weeks, and consequently a resolution of about 1/31=0.03 CPW=0.005CPD.

5.6.3 Summary

The data used for this study have a reasonable frequency resolution but lack sufficient frequency components. This means that only low frequency components can be resolved and that significance levels will tend to be lower (see Section 9). Therefore, estimates of the number of fatalities related to DST can never be precise unless high frequencies are also included in the data (see also Section 5.5).

Nevertheless, there is still significant value in these data, for it should give an indication of the existence of DST-related fatalities at the low end of the spectrum.

Since high frequency components are not in the data, it is necessary to clarify what is meant by removal of a "trend," because heretofore it has been stated that a trend is the low frequency part of the data. It is only necessary to remember that frequencies are relative, and in general, the lower the frequency, the higher the Fourier amplitude. No matter how low the frequency (except 0), there is some frequency that is even lower. Hence "trend" will be understood to refer to the lowest group of frequencies in the range of frequencies under consideration, providing this group has relatively high Fourier amplitudes. (See Section 9 for further explanations). (As shown in Reference 4, complete removal of a trend requires that the data initially contain high frequencies.)

6. APPROACH FOR ASSESSING THE IMPACT OF DAYLIGHT SAVING TIME ON MOTOR VEHICLE TRAFFIC ACCIDENT FATALITIES

This section describes the overall approach to be used in measuring changes in the number of accidents due to the influence of DST. There are two distinct parts:

1. Selection of data.
2. Selection of tests on the data.

6.1 SELECTION OF DATA

Using its regional offices as data collection points, the NHTSA surveyed all States for data on fatal traffic accidents and a limited number of States for data involving non-fatal (injury) accidents. These data were forwarded to NHTSA headquarters in Washington, D.C., for review and verification prior to being sent to TSC for analysis. All instances of data incompletion or obvious error were corrected as needed.

All States except one supplied the following data: number of persons killed in motor vehicle traffic accidents during the periods October 7, 1973 - May 11, 1974, and October 6, 1974 - May 10, 1975. Weekly counts of fatalities, Sunday through Saturday, were provided for three distinct time intervals of accident occurrence: 4 a.m. - 10 a.m., 4 p.m. - 10 p.m. and all

other times of the day. The first two time intervals include nearly all of the sunrise-sunset times in the United States.

Data on persons non-fatally injured in traffic accidents were requested from seventeen of the larger States throughout the country. These were selected on the basis of representativeness in terms of motor vehicle accidents and time zones. All four time zones were represented, each State selected falling completely within a specified zone. Thirteen States were able to provide all or most of the data requested. For these injury data, the daily time intervals of accident occurrence are identical to those specified for the fatality data (see above), but the dates of accident involvement are somewhat different. Again, the data are summarized weekly, but only for the following weeks with day beginning:

1972: December 31

1973: January 7, 14
February 11, 18, 25
March 4
April 15, 22, 29
May 6
October 14, 21, 28
November 4
December 30

1974: January 6, 13

February 10, 17, 24

March 3

April 14, 21, 28

May 5

October 13, 20, 27

November 3

December 29

1975: January 5, 12

February 9, 16, 23

March 2

April 13, 20, 27

May 4

Only the minimum amount of information considered absolutely necessary for a satisfactory qualitative analysis was requested from the States. While additional information regarding details of time of day, day of week, etc., of accident occurrence would have been preferable, schedules and severe constraints on time and other resources precluded requests for such data. Because of these constraints on the development of a more comprehensive data base for traffic fatalities and injuries, the objective of this study is to obtain estimates of the relative number of traffic fatalities

affected by DST, at low frequencies due to the weekly sampling interval involved. Highly precise estimates of the number of fatalities affected by DST are not possible with these data (See Section 5), although Section 8 does provide some approximations.

6.2 SELECTION OF TESTS ON THE DATA

This section discusses the approach for testing the data. There are two basic tests: (1) Comparing DST transition data and (2) Comparing year-to-year data. Transition data are compared for the period immediately before and after a DST transition. Year-to-year data are compared for the same dates in two or more different years, one with DST and the other without DST.

There are similar difficulties using either type of comparison, because, as shown in Section 4, trend identification is a problem in both. However, the problems associated with a transition analysis may be slightly less severe than with a year-to-year analysis because the period of time associated with the former is shorter. Typically, a transition analysis covers one to several weeks, depending on the characteristics of the data. The smaller the time period, the less likelihood for significant changes in trends to obscure the effects of DST on the accident population. A year-

to-year comparison would require up to several months of data to raise confidence levels, because, in this case, there is a greater likelihood for significant changes in the accident population from one year to the next. For instance, one of the consequences of the oil embargo of early 1974 was a reduction in speed limits and a subsequent decrease in traffic accidents and traffic deaths from the year before. However, since DST was also in effect during the same period of time during 1974 (i.e., early in the year), whereas DST did not go into effect until late April of the previous year, discrimination between reduced fatalities in early 1974 (compared to early 1973) due to DST and those due to the oil embargo and reduced speed limits is not a simple matter, although this distinction was made in the Congressional study.[1] In view of these considerations, it would seem preferable to concentrate on transition studies and discard year-to-year comparisons altogether. This, however, is not recommended because the ultimate goal of such a study is to determine the proportion of accidents influenced by DST, and this is best done by year-to-year comparisons which involve longer periods of time extending over the same season and, as a consequence, significantly greater amounts of data. Nonetheless, transition analyses are good indicators of the existence (and magnitude) of DST-related effects. If no such effects can be detected in the

transitions, it is even less likely that they will show up in the year-to-year comparisons.

With this introduction to the pros and cons of using transition and year-to-year analyses for this study, the calendar dates selected for each type of test were:

1. Transitions: Week of October 28, 1973
January 6, 1974
October 27, 1974
February 23, 1975

2. Year-to-Year:

DST: January 6, 1974, to February 16, 1974
No DST: January 5, 1975, to February 15, 1975

7. DATA REDUCTION OF TRAFFIC FATALITIES

This section will explain the techniques used to test for the existence of a DST effect on traffic fatalities, and to obtain estimates of the magnitude of this effect. Four principal techniques were used: (1) Digital filtering, (2) Development of criteria for comparing changes in fatalities across a DST transition, (3) Inter-Year comparisons and (4) Tests of significance of changes in fatalities due to DST.

7.1 DIGITAL FILTERING

The raw data curves in Figures 4-3 and 4-4 show that during the first week following the transition from DST to ST on October 28, 1973 (i.e., during the fourth week shown in each figure), fatalities decreased in the morning and increased in the evening, as predicted by the DST hypothesis. However, filtering out the (relatively) low frequencies, that is, removing the largest trend within the trend region (see Section 5), yields a better numerical estimate of those fatalities influenced by DST.

It is also interesting to note that following the transition to DST on February 23,1975, the actual number of morning fatalities decreased (see week number 21 in Figure 4-5), contrary to the DST hypothesis. However, for the same

period of time, the corresponding filtered fatalities increased, as predicted by the DST hypothesis (see week number 21 in Figure 7-3).

All raw data fatality were passed through an 0.03-0.5 CPW filter and then processed further by the method described in Section 5.3. The filtered data for the morning and evening hours, week of October 7, 1973 - May 5, 1974, are plotted in Figure 7-1 and Figure 7-2. The corresponding weekly data for the period October 6, 1974 - May 4, 1975, are shown in Figures 7-3 and 7-4. Actual (percentage) differences in filtered fatalities across all transitions and between successive years are summarized in Section 8.

7.2 COMPARISON OF FATALITIES BEFORE AND AFTER A DST TRANSITION

For both the morning and evening time periods (4 a.m.-10a.m., 4 p.m.-10p.m.), the number of filtered fatalities one week before a transition were compared with the number one week after in the following manner. For each time interval, weekly sums of filtered fatalities were normalized to (i.e., divided by) the total number of raw fatalities occurring during that week (24 hour basis) and the percentage changes in filtered fatalities for morning and evening hours were then compared. Experience acquired in the initial study of the effects of DST (Reference 1) indicated that if normalization were less than 24 hours, results

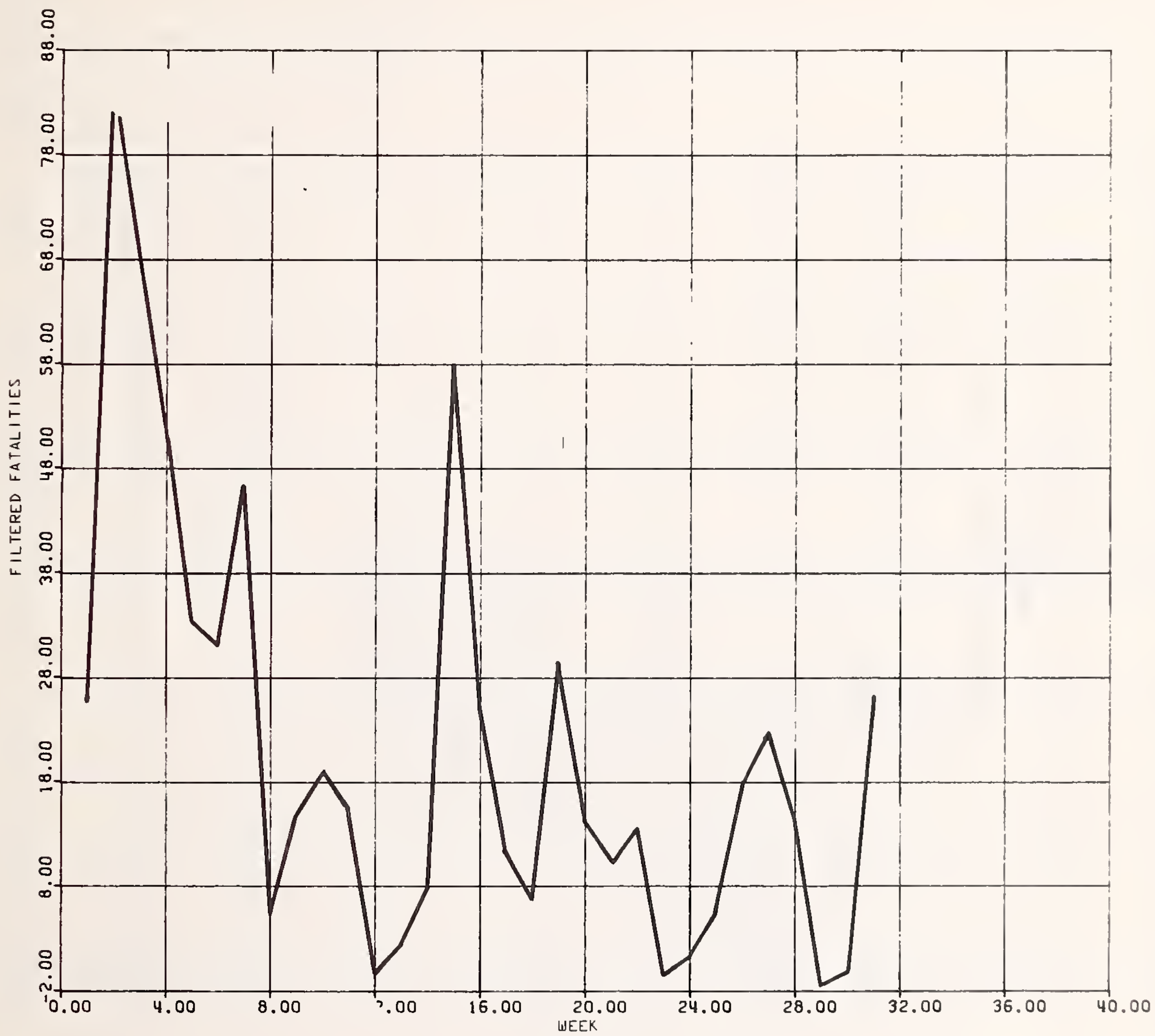

FIGURE 7-1. FILTERED (TOTAL U.S.) FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 7, 1973 - MAY 5, 1974, 4AM-10AM. Bandwidth: 0.03 - 0.5 Cycles/Week.

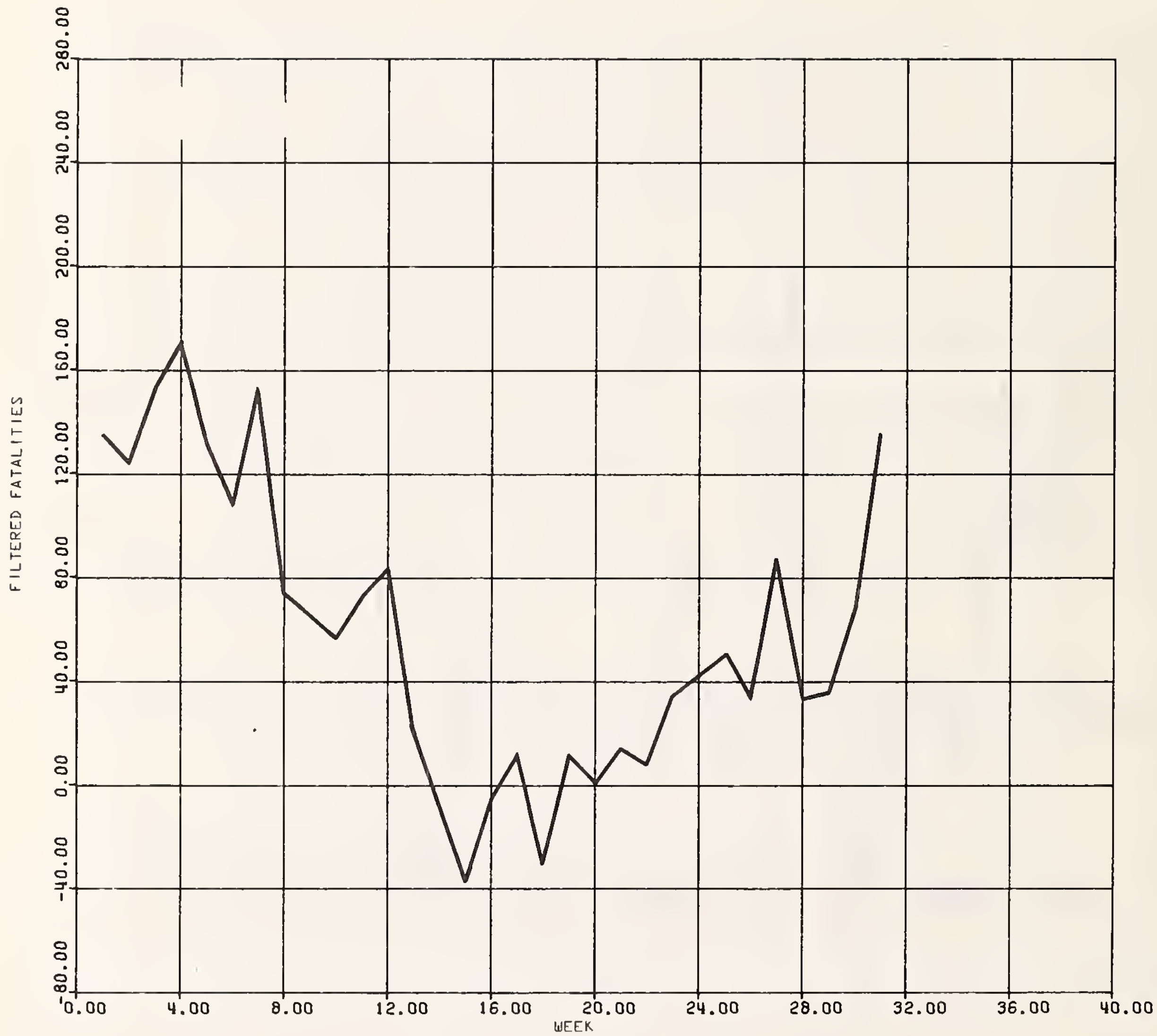

FIGURE 7-2. FILTERED (TOTAL U.S.) FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 7, 1973 - MAY 5, 1974, 4PM-10PM. Bandwidth: 0.03 - 0.5 Cycles/Week.

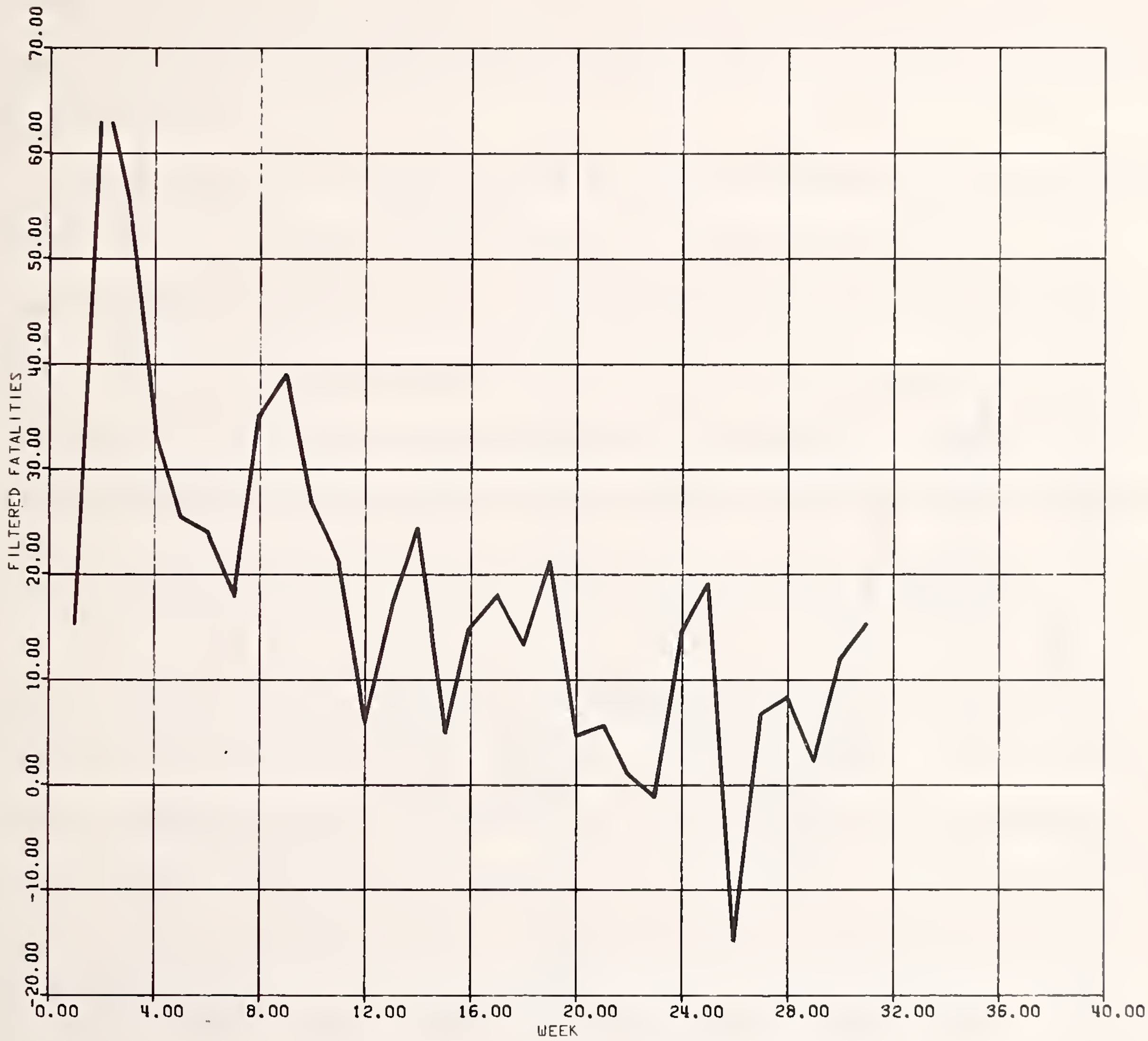

FIGURE 7-3. FILTERED (TOTAL U.S.) FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 6, 1974 - MAY 4, 1975, 4AM-10AM. Bandwidth: 0.03 - 0.5 Cycles/Week.

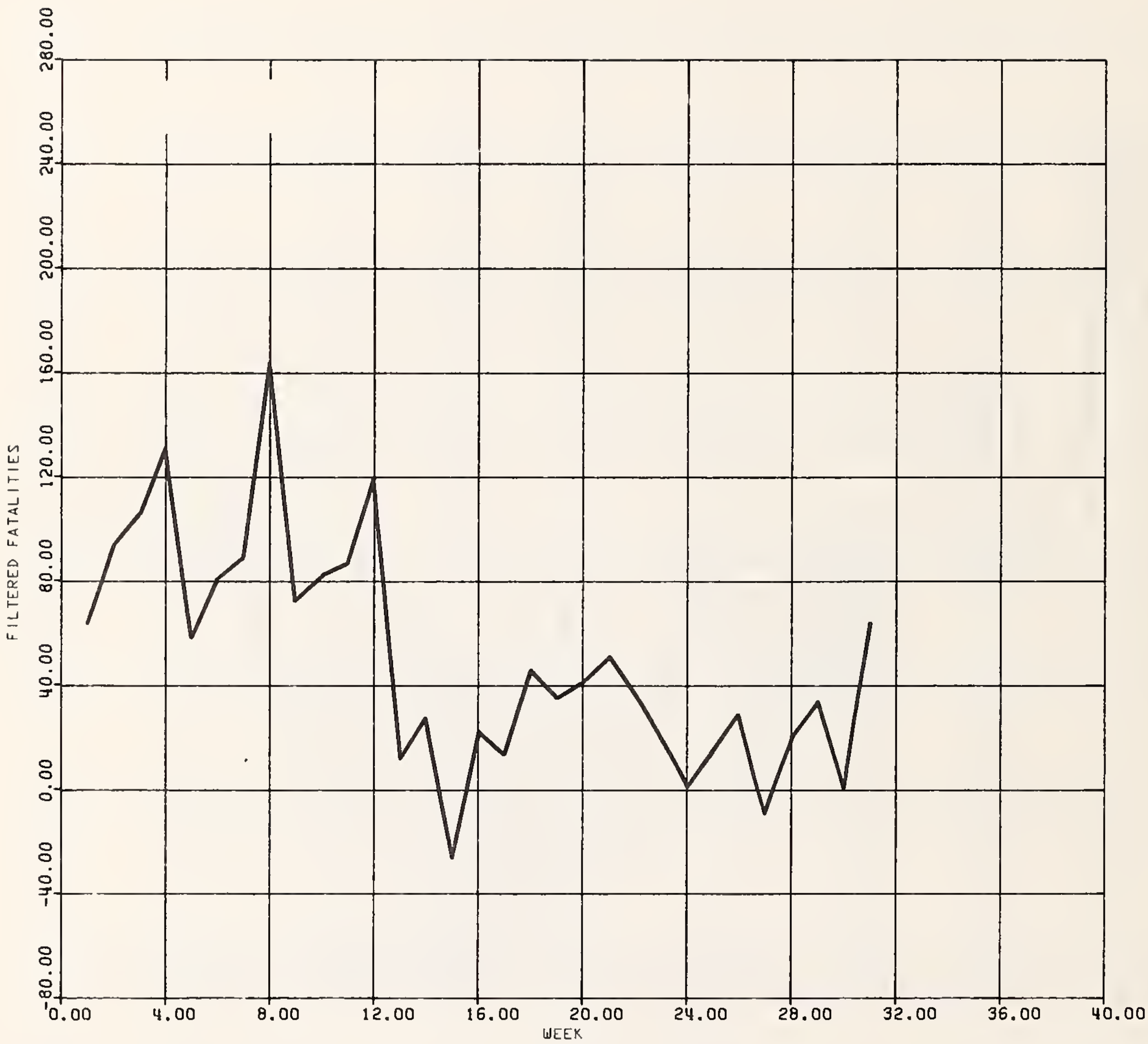

FIGURE 7-4. FILTERED (TOTAL U.S.) FATALITIES FROM MOTOR VEHICLE TRAFFIC ACCIDENTS, WEEK OF OCTOBER 6, 1974 - MAY 4, 1975, 4PM-10PM. Bandwidth: 0.03 - 0.5 Cycles/Week.

would be inaccurate due to a smaller accident population. With a larger accident population, the accident distribution tends to be normal.

In regard to the time period being compared, it is believed that use of a larger normalization interval would lead to conservative results, i.e., underestimates of the effect of DST. Thus, a comparison involving more than one week before and after a transition would tend to reduce the sensitivity of the comparison, for trend effects are more likely to adversely influence comparisons over relatively long intervals.

For example, some trends are caused or influenced by sunrise and sunset times that change by significant amounts over a brief interval of several weeks. This is particularly true following the transition to Standard Time in October. In this case, there is one more hour of light in the morning which should reduce fatalities. However, the amount of natural morning light is also rapidly decreasing at this time. This should result in an increase in fatalities which will tend to obscure the effect of changing to Standard Time (See Section 3).

Secondly, limiting tests to one week before and after a transition is particularly necessary for the October transition because of data limitations. Since each full transition is positioned near the start of a time series, trend removal could become inaccurate for weeks very early in

October. (Note that trend estimation tends to become inaccurate near the start and end of a time series.)

7.3 INTER-YEAR COMPARISONS

These involve a comparison of several (DST) weeks in early 1974 with a corresponding (non-DST) period in early 1975. There are also two additional control intervals; the first covering several weeks just before the DST period in question and the second extending several weeks just after it. By comparing changes in (filtered) fatalities from 1974 to 1975 for each of the three intervals specified, the DST hypothesis was confirmed (see Section 8).

7.4 TESTS OF SIGNIFICANCE OF THE DST HYPOTHESIS

The best test of the DST hypothesis is to examine as many DST transitions as possible and thereby determine if the predictions of the hypothesis are verified. However, because only a limited number of transitions were available, formal tests of statistical significance were also used. Essentially, these tests involved a determination of the probability that random (filtered) data would have to led to larger changes in fatalities at a DST transition than were actually measured. Statistical tests of significance were also applied to changes in (filtered) fatalities at control transitions (i.e. non-transitions)

in the same year as the real transition and also one year after the real transition, if the latter did not repeat itself as a transition period (e.g., January 6, 1974 vs. January 5, 1975). Tests were applied to both the morning and evening fatality time series. Some changes in fatalities at the non-transitions were found to be statistically less significant than corresponding changes at the actual transition. This resulted in greater confidence that DST was really the cause of the change at the actual transition (Section 9 summarizes the significance levels).

The significance of the difference in (filtered) fatalities from the week before to the week after a transition was tested by comparison with the standard deviation of weekly differences in (filtered) fatalities for the entire fatality time series. A standard t-test was used, as follows:

$$t = D(j)/s \tag{7-1}$$

where D(j) is the difference in filtered fatalities between two consecutive weeks j and j-1, that is, one week following and one week before a transition, and s, the standard deviation of weekly differences, is given by

$$s = \left[\left(\sum_{\substack{j=3 \\ j \neq 6}}^{30} D^2(j) - N\bar{D}^2 \right) / (N-1) \right]^{1/2} \qquad (7\text{-}2)$$

with the mean $\bar{D}$ given by

$$\bar{D} = \sum_{\substack{j=3 \\ j \neq 6}}^{30} D(j)/N \qquad (7\text{-}3)$$

where N is the number of samples and 6 is the transition being tested. (Testing against weekly differences in fatalities may have helped to de-trend the data even more, thereby leading to a more accurate estimate for t than if testing had not been made against these differences.) To prevent biases in s, the summations relating to s did not include the two-week transition period being tested. Ideally, the standard deviation should be a measure of the inherent scatter in a randomly distributed population. However, because the DST model predicts a pulse at the transition, the sample would no longer be randomly distributed if fatalities at the transition were included in the summations of Equations (7-2) and (7-3). For instance, at the control transition from week 5 to week 6, the summations in Equations (7-2) and (7-3) omit D(j=6), i.e., differences in fatalities between weeks 5 and 6.

Summation over the first two weeks (j=1 and j=2) and the last week (j=31) in these time series was also excluded because

the ends of the series are virtually discontinuities, and inclusion of these terminal samples could lead to errors in final results. (Note: processing samples at the beginning and end of fatality time series was also avoided in Reference 1). The second week at the beginning of the time series (j=2) was excluded because it includes differences between itself and the first week.

A one-tailed t-test was used at real transitions, and a two-tailed t-test at all control transitions because, at the actual transition, theory predicts the sign of the change, whereas the sign is not predictable at control transitions.

8. ESTIMATES OF CHANGES IN MOTOR VEHICLE TRAFFIC ACCIDENT FATALITIES DUE TO DAYLIGHT SAVING TIME

This section estimates the effects of DST transitions on motor vehicle traffic fatalities. All four transitions in the data were analyzed; October 28, 1973, January 6, 1974, October 27,1974, and February 23,1975. A control transition on January 5, 1975 was also analyzed, and a comparison of filtered fatalities was made between the interval January 6,1974-February 16,1974 (DST) and January 5,1975-February 15,1975 (no DST). Four inter-year control intervals, each of seven weeks duration, were also compared. Two of these control intervals preceded that of January-February and had no DST effect during both years. The remaining two control intervals succeeded the January-February interval and had DST in effect during both years. In all tests - transitions and inter-year, the results are consistent with the DST hypothesis.

In Tables 8-1 to 8-10, filtered fatalities are summarized for the indicated time intervals, one week before and one week after each transition, while "total fatalities" summarizes all weekly raw data on a complete 24 hour basis during the two-week period under study (See Section 7).

8.1 DST TRANSITIONS ON OCTOBER 28, 1973 AND OCTOBER 27, 1974

Table 8-1 summarizes changes in traffic fatalities at the Fall 1973 DST transition. Across the transition the relative number of morning fatalities decreased by 1.29 percent while in the evening there was an increase of 2.44 percent, resulting in a net increase of 1.2 percent.

The results of the analysis of the DST transition in the Fall of 1974 are summarized in Table 8-2. The DST hypothesis is verified but fatalities increased across the transition by 0.74 percent compared to 1.2 percent for the Fall 1973 transition. However, each of these two sets of measurements may be regarded as statistically independent samples of (filtered) fatalities which can be combined for both years. Therefore, the time series commencing with October 7,1973 was first filtered and then algebraically added to the filtered time series commencing with October 6,1974. Corresponding data were combined for both years; morning and evening fatalities, one week before and one week after each transition. Table 8-3 summarizes these results. The bottom figures in this table indicate the average change in filtered fatalities for both years. These average results for the Fall transition to Standard Time during these two years verify the DST hypothesis and there was a net average increase in fatalities of 0.95 percent after switching to Standard Time.

Of all data analyzed in this section, it is believed that the October transition data are the most reliable.

8.2 DST TRANSITION ON JANUARY 6, 1974

On January 6,1974, the U.S. switched from Standard Time to DST. Table 8-4 summarizes the effect of this transition on traffic fatalities. The changes in fatalities verify the DST hypothesis. The overall reduction in fatalities was computed to be 4.4 percent.

If the calculations for Table 8-4 are repeated using raw fatality data instead of filtered fatalities, a 58 percent increase in fatalities is computed. These results are summarized in Table 8-5 and are mentioned here merely to indicate the need for data filtering. That is, an analysis based on raw (unfiltered) data may be entirely misleading and, as in the present instance, may not confirm the DST hypothesis.

Although the 4.4 percent reduction indicated above for filtered data is impressive, it should be regarded with caution, for it is intrinsically difficult to analyze data around the Christmas - New Year holiday season without very elaborate analyses that take into account all fatality spectrum frequencies, especially high frequencies.

8.3 CONTROL TRANSITION ON JANUARY 5, 1975

A comparison of changes in motor vehicle traffic fatalities at the real transition on January 6, 1974 with those at the control transition on January 5, 1975 serves as a check on the DST hypothesis. Comparing Tables 8-4 and 8-6 shows that morning fatalities continued to increase across both the real and control transitions. However, evening fatalities also continued to increase across the control transition. There was a DST effect at the real transition but not at the control transition. These results are consistent with the DST hypothesis. However, because so few comparisons of this type were possible, they are not absolute proof of a bona fide DST effect.

8.4 DST TRANSITION ON FEBRUARY 23, 1975

On February 23,1975, the U.S. switched from Standard Time to DST. The results of the analysis to assess effects of DST on motor vehicle traffic fatalities at this time are summarized in Table 8-7. The percentage of morning fatalities increased by 0.11 percent across the transition, as predicted by the DST hypothesis, but the percentage of evening fatalities also increased (1.18 percent), whereas the DST hypothesis predicts that it should have decreased. It might at first appear that

this is a contradiction to the hypothesis but actually it is another verification. Section 3 points out that DST-related fatalities should occur primarily during the peak of the morning (7AM-9AM) and evening (4PM-6PM) rush hours, if sunrise and sunset also occur during these hours. It is also pointed out that since most sunsets in the vicinity of February 23 occur after 6 PM (for both DST and Standard time), little or no DST effect can be expected during the evening at this time.

8.5 YEAR-TO-YEAR COMPARISONS OF DST EFFECTS

The intervals chosen for comparison were January 6,1974-February 16, 1974 (DST) and January 5, 1975 - February 15, 1975 (no DST). The results are summarized in Table 8-8. There was an overall increase of about 4 percent in fatalities in 1975, compared with 1974. Morning fatalities for 1975 were down 1.5 percent compared to the same period in 1974, which is consistent with the DST hypothesis. The relative increase of 5.5 percent for evening fatalities is also consistent with the DST hypothesis.

It is very likely that DST did influence these results. For example, a similar calculation for the preceeding seven week interval (see Table 8-9) yields an 0.97 percent increase in fatalities during the morning, whereas Table 8-8 shows a 1.45 percent decrease. Table 8-10, which summarizes the

results for the succeeding seven weeks, shows a 3.06 percent decrease in evening fatalities. Only Table 8-8, which compares a DST interval with a non-DST interval, has the predicted sign changes in morning and evening.

Tables 8-8, 8-9, and 8-10 do not reflect the average of filtered fatalities over the number of weeks involved (7), but the results shown for these entire seven-week periods are sufficient for purposes of comparison. With averaging, Table 8-8 would show an adjusted percent change of 0.57 percent which is in excellent agreement with the change of 0.95 percent in Table 8-3.

TABLE 8-1. MOTOR VEHICLE TRAFFIC FATALITY CHANGES AT THE FALL 1973 TRANSITION FROM DST. Total U.S. The Bandwidth is 0.03-0.5 Cycle/Week.

	One Week Before Transition (DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	67	153	-
Total Fatalities	-	-	1006
Filtered Percent of Total	6.66	15.21	-

	One Week After Transition (No DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	52	171	-
Total Fatalities	-	-	969
Filtered Percent of Total	5.37	17.65	-

	4AM-10AM	4PM-10PM	Total Change
Change in Number of Filtered Fatalities	-15	18	+3
Change in Filtered Fatalities, percent	-1.29	2.44	+1.2

TABLE 8-2. MOTOR VEHICLE TRAFFIC FATALITY CHANGES AT THE FALL 1974 TRANSITION FROM DST. Total U.S. The Bandwidth is 0.03-0.5 Cycle/Week.

	One Week Before Transition (DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	56	106	-
Total Fatalities	-	-	818
Filtered Percent of Total	6.85	12.96	-

	One Week After Transition (No DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	34	132	-
Total Fatalities	-	-	808
Filtered Percent of Total	4.21	16.34	-

	4AM-10AM	4PM-10PM	Total Change
Change in Number of Filtered Fatalities	-22	26	+4
Change in Filtered Fatalities, percent	-2.64	3.38	+0.74

TABLE 8-3. CUMULATIVE MOTOR VEHICLE TRAFFIC FATALITY CHANGES AT THE FALL TRANSITIONS FROM DST IN 1973 AND 1974. Total U.S. The Bandwidth is 0.03-0.5 Cycle/Week.

	One Week Before Transition (DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	123	259	-
Total Fatalities	-	-	1824
Filtered Percent of Total	6.74	14.20	-

	One Week After Transition (No DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	86	303	-
Total Fatalities	-	-	1777
Filtered Percent of Total	4.84	17.05	-

	4AM-10AM	4PM-10PM	Total Change
Average Change in Number of Filtered Fatalities for 1973 and 1974	-19	22	+3
Average Change in Filtered Fatalities for 1973 and 1974, percent	-1.90	2.85	+0.95

TABLE 8-4. MOTOR VEHICLE TRAFFIC FATALITY CHANGES AT THE JANUARY 6, 1974 TRANSITION TO DST. Total U.S. The Bandwidth is 0.03-0.5 Cycle/Week.

	One Week Before Transition (No DST)		
	4AM-10AM	4PM-10PM	24 hrs
Filtered Fatalities	2	22	-
Total Fatalities	-	-	571
Filtered Percent of Total	0.35	3.85	-

	One Week After Transition (DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	8	-9	-
Total Fatalities	-	-	484
Filtered Percent of Total	1.65	-1.86	-

	4AM-10AM	4PM-10PM	Total Change
Change in Number of Filtered Fatalities	6	-31	-25
Change in Filtered Fatalities, percent	1.30	-5.71	-4.41

TABLE 8-5. MOTOR VEHICLE TRAFFIC FATALITY CHANGES AT THE JANUARY 6,1974 TRANSITION TO DST. Total U.S. No Filtering.

	One Week Before Transition (No DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	-	-	-
Total Fatalities	77	84	571
Percent of Total Fatalities	13.5	14.7	-

	One Week After Transition (DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	-	-	-
Total Fatalities	222	193	484
Percent of Total Fatalities	45.9	39.9	-

	4AM-10AM	4PM-10PM	Total Change
Change in Total Fatalities, percent	32.4	25.2	57.6

TABLE 8-6. MOTOR VEHICLE TRAFFIC FATALITY CHANGES AT THE JANUARY 5, 1975 CONTROL TRANSITION. Total U.S. The Bandwidth is 0.03-0.5 Cycle/Week.

	One Week Before Transition (No DST)		
	4AM-10AM	4PM-10PM	24 hrs
Filtered Fatalities	17	11	-
Total Fatalities	-	-	692
Filtered Percent of Total	2.5	1.6	-

	One Week After Transition (No DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	24	28	-
Total Fatalities	-	-	575
Filtered Percent of Total	4.2	4.9	-

	4AM-10AM	4PM-10PM	Total Change
Change in Number of Filtered Fatalities	7	17	24
Change in Filtered Fatalities, percent	1.7	3.3	5.0

TABLE 8-7. MOTOR VEHICLE TRAFFIC FATALITY CHANGES AT THE FEBRUARY 23,1975 TRANSITION TO DST. Total U.S. The Bandwidth is 0.03-0.5 Cycle/Week.

	One Week Before Transition (No DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	5	41	-
Total Fatalities	-	-	596
Filtered Percent of Total	0.84	6.88	-

	One Week After Transition (DST)		
	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	6	51	-
Total Fatalities	-	-	633
Filtered Percent of Total	0.95	8.06	-

	4AM-10AM	4PM-10PM	Total Change
Change in Number of Filtered Fatalities	1	10	11
Change in Filtered Fatalities, percent	0.11	1.18	1.29

TABLE 8-8. MOTOR VEHICLE TRAFFIC FATALITY COMPARISONS. Total U.S. January 6,1974-February 16,1974 (DST) vs. January 5,1975-February 15,1975 (No DST). The Bandwidth is 0.03-0.5 Cycle/Week.

January 6, 1974-February 16, 1974 (DST)	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	151	-59	-
Total Fatalities	-	-	3800
Filtered Percent of Total	3.97	-1.55	-

January 5,1975-February 15, 1975 (No DST)	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	102	158	-
Total Fatalities	-	-	4046
Percent of Total Fatalities	2.52	3.91	-

	4AM-10AM	4PM-10PM	Total Change
Change in Number of Filtered Fatalities	-49	217	168
Change in Filtered Fatalities, percent	-1.45	5.46	4.01

(Average change = 0.57 percent)

TABLE 8-9. MOTOR VEHICLE TRAFFIC FATALITY COMPARISONS. Total U.S. November 18,1973-January 5,1974 (No DST) vs. November 17,1974-January 4,1975 (No DST). The Bandwidth is 0.03-0.5 Cycle/Week.

November 18,1973-January 5,1974 (No DST)	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	103	524	-
Total Fatalities	-	-	5088
Filtered Percent of Total	2.02	10.30	-

November 17,1974-January 4,1975 (No DST)	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	162	625	-
Total Fatalities	-	-	5413
Filtered Percent of Total	2.99	11.55	-

	4AM-10AM	4PM-10PM	Total Change
Change in Number of Filtered Fatalities	59	101	160
Change in Filtered Fatalities, percent	0.97	1.25	2.22

TABLE 8-10. MOTOR VEHICLE TRAFFIC FATALITY COMPARISONS. Total U.S. February 24,1974-April 7,1974 (DST) vs. February 23,1975-April 6,1975 (DST). The bandwidth is 0.03-0.5 Cycle/Week.

February 24,1974-April 7,1974 (DST)

	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	70	269	-
Total Fatalities	-	-	4192
Filtered Percent of Total	1.67	6.42	-

Febuary 23,1975-April 6,1975 (DST)

	4AM-10AM	4PM-10PM	24 hrs.
Filtered Fatalities	30	141	-
Total Fatalities	-	-	4191
Percent of Total Fatalities	0.72	3.36	-

	4AM-10AM	4PM-10PM	Total Change
Change in Number of Filtered Fatalities	-40	-128	-168
Percent Change in Filtered Fatalities	-0.95	-3.06	-4.01

8.6 COMPARISON OF ESTIMATES WITH THOSE OBTAINED IN CONGRESSIONAL STUDY

8.6.1 Interyear Comparisons, 1973, 1974, 1975

This section calculates an interyear estimate (1973, 1974, 1975) of the average change in traffic fatalities due to DST using data from both Reference 1 and the present study combined. Because the data bases involved are different, an accurate comparison between the two studies is not possible. For example: (1) Reference 1 compares 1973 with 1974, whereas the current study compares 1974 with 1975, (2) the bandwidths are different, (3) the observation times for each year are different, (9 weeks for the earlier study vs. 7 weeks for this study). (4) Reference 1 excludes weekends whereas this study includes them, and (5) morning and evening time intervals are slightly different. These five differences can be partially compensated for as follows: (1) Assume that the effects of DST on traffic fatalities in each bandwidth are statistically independent of one another. (2) 1973 and 1975 are the same in that each had no DST in effect during January and February (only the end of February 1975 had DST), (3) adjust the difference in the length of a typical week and the number of weeks in each study. Details of this adjustment follow.

Data from Table 8-8 of this report and from Table 7.5-13 of Reference 1 (Volume II), as indicated in the calculations of this section, are adjusted by the following factors to render them comparable with one another:

(1) The factors 0.75 and 0.68 reduce the filtered fatality data of Table 8-8 for Jan-Feb 1975, morning and evening hours, respectively, from 7 days a week to only 5 days a week (i.e. Monday-Friday). During this period, 75% of the deaths occurring between 4AM and 10AM each week, and 68% of the deaths occurring between 4PM and 10PM, actually took place during these hours on Monday through Friday.

(2) Similarly, the factors 0.76 and 0.67 reduce Table 8-8 filtered fatality data for Jan-Feb 1974, morning and evening hours, respectively, from 7 days a week to the 5 weekdays.

(3) The factors 0.65 and 0.66 reduce the total 24-hour unfiltered fatality data of Table 8-8, for Jan-Feb 1975 and Jan-Feb 1974, respectively, from 7 days a week to 5 days, Monday-Friday. During January and February of 1975, 65% of all deaths each week occurred between Monday and Friday. This figure was 66% for January and February, 1974.

(4) The factors 1.15 and 1.48, respectively, increase the morning and evening hour intervals of filtered fatality data from Table 7.5-13 for Jan-Feb 1974. Thus, 1.15 expands the morning time interval to 4-10AM, while 1.48 expands the evening time interval to 4-10PM. During January and February of 1974, Monday through Friday, 1.15 times as many traffic deaths occurred between 4-10AM as occurred between 6-10AM, while 1.48 more deaths occurred from

4-10PM as occurred from 4-8PM.

(5) Similarily, the facotrs 1.19 and 1.36, respectively, increase the morning and evening hour intervals of filtered fatality data from Table 7.5-13 for Jan-Feb 1973.

(6) Finally, the factor 0.5 adjusts corresponding results from both studies for differences in number of observations involved. This factor is applied to the summation of adjusted data from Table 8-8 and Table 7.5-13. This adjustment is necessary because Reference 1 used 9 weeks of data for the Interyear Comparison whereas this study uses only 7. Rather than applying some ratio consisting of the digits 9 and 7, which fails to properly adjust for percentage differences between the two studies due to differences in denominatior size, it is statistically preferable to obtain the simple arithmetic mean of corresponding percentages. This has the effect of equalizing the number of observations used in each study and, as a result, the percentage averages obtained for both studies combined reflect equal weighting given to the results of each study. Let

P1 = Average percentage of filtered motor vehicle traffic fatalities in the morning, Jan-Feb 1974 (DST)

$$= (0.5)[(151)(0.76)/(3800)(0.66) + (29)(1.15)/2817] = 2.88\%$$

P2 = Average percentage of filtered motor vehicle traffic fatalities in the morning, Jan-Feb 1975/1973 (No DST)

$$= (0.5)[(102)(0.75)/(4046)(0.65) + (13)(1.19)/2769] = 1.73\%$$

P3 = Average percentage of filtered motor vehicle traffic fatalities in the evening, Jan-Feb 1974 (DST)

$$= (0.5)[(-59)(0.67)/(3800)(0.66) + (31)(1.48)/2817] = -0.03\%$$

P4 = Average percentage of filtered motor vehicle traffic fatalities in the evening, Jan-Feb 1975/1973 (No DST)

$$= (0.5)[(158)(0.68)/(4046)(0.65) + (52)(1.36)/2769] = 3.32\%$$

Combining the P's:

$$(P2-P1) + (P4-P3) = (1.73-2.88)\% + (3.32 + 0.03)\% = 2.20\%$$

Thus, during Jan-Feb 1975/1973, when DST was not in effect, there was a relative increase in fatalities of 2.20%, compared to the same period of 1974 when DST was in effect. The foregoing numerical estimates are, at best, very qualitative. All that can be definitely stated in this regard is that both studies indicate a decrease in traffic deaths for DST periods of one year compared with similar, non-DST periods of other years.

8.6.2 Fatalities at the October 1973 Transition (From DST)

The average change in traffic fatalities due to this transition is estimated by again combining the results of this study with those of Reference 1. Data from Table 8-1 of this report and from Tables 7.5-3 and 7.5-4 of Reverence 1 (Volume II) are initially adjusted by the following factors to render them comparable with one another:

(1) The factors 0.71 and 0.67 reduce the filtered fatality data of Table 8-1 for October-November 1973, morning and evening hours, respectively, from 7 days a week to only 5 days a week (i.e., Monday-Friday). During this period, 71% of the deaths occurring between 4AM and 10AM each week, and 67% of the deaths occurring between 4PM and 10PM, actually took place during these hours on Monday through Friday.

(2) The factor 0.64 reduces the total 24-hour unfiltered fatality data of Table 8-1 for October-November 1973 from 7 days a week to 5 days, Monday-Friday. During October and November of 1973, 64% of all deaths each week occurred between Monday and Friday.

(3) The additional factor 0.5 adjusts corresponding results from both studies for differences in number of observations involved. As already noted in the previous section, this factor results in the simple arithmetic mean of corresponding percentages, giving equal weight to the results of each study. In this case, the adjustment is necessary because Reference 1 used 6 and 10 weeks of data to study the October 1973 transition, 6 weeks for the evening hours and 10 for the morning hours, whereas the present study uses only 2 weeks of data, and usage of numbers 3 and 5 as multiplication factors applied to Table 8-1 data fails to properly adjust for percentage differences between the two studies due to differences in denominator size. Let

P1 = Average percentage of filtered motor vehicle traffic fatalities in the morning, October 1973, before transition (DST)

$$= (0.5)[(67)(0.71)/(1006)(0.64) + 5/2972] = 3.78\%$$

P2 = Average percentage of filtered motor vehicle traffic fatalities in the morning, October 1973, after transition (No DST)

$$= (0.5)[(52)(0.71)/(969)(0.64) - 5/2652] = 2.88\%$$

P3 = Average percentage of filtered motor vehicle traffic fatalities in the evening, October 1973, before transition (DST)

$$= (0.5)[(153)(0.67)/(1006)(0.64) - 6/1776] = 7.79\%$$

P4 = Average percentage of filtered motor vehicle traffic fatalities in the evening, October 1973, after transition (No DST)

$$= (0.5)[(171)(0.67)/(969)(0.64) + 18/1652] = 9.78\%$$

Combining the P's:

$$(P2-P1) + (P4-P3) = (2.88-3.78)\% + (9.78-7.79)\% = +1.09\%$$

Thus, due to the October 1973 transition from DST to Standard Time, the results of both studies combined indicate a relative increase in fatalities of 1.09%. Again, however, all that can be definitely stated in this regard is that both studies indicate an increase in traffic deaths following this transition. These calculations, albeit very qualitative, show that DST reduces motor vehicle traffic fatalities by somewhere between 1%-2% (1.09%, 2.20%), depending on whether the comparison is made before and after transition, or year-to-year. This near agreement is indicative of a DST effect but a more quantative study would be required to substantiate these results.

9. STATISTICAL SIGNIFICANCE OF CHANGES IN FATALITIES DUE TO DST

In order to ascertain the statistical significance of changes in fatalities, that is, the probability that random data would have yielded larger deviations than those observed (see Section 8), two steps were taken; (1) The net change in (filtered) fatalities was computed at numerous control transitions (i.e., randomly selected dates when a DST transition did not occur) as well as at the real DST transitions, and (2) The statistical significance of these changes in fatalities was computed for both the actual and the control transitions. If changes at control transitions in proximity of a real transition were found to be statistically less significant than the change at the transition itself, this resulted in greater confidence that DST was the cause of the change at the real transition.

However, this calculated statistical significance is to a great extent subject to certain practical limitations. Because many factors as well as DST influence changes in fatalities, large significances at a few control transitions do not necssarily mean that the change at the real transition was not significant. Therefore, in addition to formal rules for computing levels of significance, some common sense rules were also applied, as follows: (1) Changes in (filtered) fatalities at many real transitions which were always in the direction

predicted by the DST hypothesis resulted in greater confidence that the change was due primarily to DST, (2) Significance levels of actual DST transitions were compared with those of control transitions when both had like sign in changes in fatalities and (3) The number of plus and minus changes at control transitions had to be roughly the same. Two factors reduce the significance at DST transitions: (1) A limited number of data samples in each fatality time series, and (2) Weekend fatalities included in the data (see Sections 3 and 4).

Table 9-1 summarizes the results of the significance tests for weekly changes in fatalities occurring between 4AM - 10AM from October 7,1973-May 5,1974, and Table 9-2 summarizes similar results for the corresponding 4 p.m.-10 p.m. time period. Table 9-3 summarizes the results for the weeks of October 6,1974-May 4,1975, 4 a.m.-10 a.m., and Table 9-4 for the corresponding 4 p.m.-10 p.m. time period. The significance is regarded as high if the probability is actually very small (approaches 0).

In Table 9-1, the significances of fatality changes for the real transition between the 3rd and 4th weeks and between the 13th and 14th weeks are 16 percent and 38 percent, respectively. There are several other important observations: First, the significance at the fourth week is higher (i.e., lower probability) than most other significances in its

vicinity. Second, the sign of the change in fatalities at this transition is negative, as predicted by the DST hypothesis.

While the probability at the fourteenth week is somewhat high, it is still lower than most other probabilities. The principal difficulty in this case is that the holiday season (week 14 begins on Sunday, January 6) tends to obscure the relatively small differences in fatalities due to DST. A similar comment applies to Table 9-2, where the probability at week 14 (i.e., 18 percent), though still high, is nonetheless lower than the ones at the majority of the control transitions. Note that the relatively higher significance for the evening hours compared to the morning hours (18 percent versus 38 percent) of the real transition to DST at week 14 is consistent with the general observation made in Section 3 that this is so because the traffic pattern at the transition is changing with time more rapidly in the evening than in the morning (see Section 3 and Figure 3-1). For a similar reason, the morning hours of the real transition at the fourth week have a higher significance than the evening hours.

In Table 9-3, the significance of fatality changes for the morning hours of the transition from DST at the 4th week, 4 percent, is excellent. On the other hand, the 45 percent significance for the morning hours of the transition at the 21st week (February 23, 1975) is not very good but is to be

expected since morning traffic at this time does not change very rapidly across the shaded area (see Figure 3-3).

In Table 9-4, the significance of fatality changes for the evening hours of the DST transition at the fourth week is fairly good (27 percent) in comparison with significance levels at most control transitions. However, the evening hours of the DST transition at week number 21 do not have and are not expected to have a high level of significance (41 percent) because most sunsets at this time occur after the peak of the evening rush hour for both DST and Standard Time (see Section 3 and Figure 3-3).

Fatality changes are more significant for the morning than for the evening hours of the October transition from DST. This is indicated in Figure 3-2 where the slope of the travel curve across the shaded area is greater for the morning hours (see Section 3). It is in the relatively flat part of the travel curve where additional high frequency components are needed (but least likely to be generated) for accurate (i.e., statistically significant) measurements. Also note the second order terms which are functions of ΔN in Equation (5-11). If ΔN becomes large, which is most likely to occur on the rise part of the travel curve, $d|F|/dE$ approaches zero, thereby minimizing the influence of biases in measuring changes in (filtered) fatalities across the transition. Hence, significances are larger and biases are smaller where the slope

of the travel curve is greater. (These explanations also apply to the January transitions.)

The most meaningful tests of the statistical significance of differences in fatalities were for the October transition in 1973 and 1974, because, for the data available for this study, no other transition took place at the same date in different years. Table 9-5 summarizes the "Sign Consistency" of weekly changes in filtered fatalities for the morning hours of both time periods combined: October 7, 1973 - May 5, 1974 and October 6, 1974 - May 4, 1975. Table 9-6 does the same for the corresponding evening hours. Sign Consistency specifies if the algebraic sign of the change in number of fatalities at each DST transition is consistent with the DST hypothesis. The abbreviation Y means that there is consistency in both years; N means there is no consistency in at least one of the years. Table 9-7 summarizes the Sign Consistency for all morning and evening hours combined for both time periods. In this case, there are 21 N's and 7 Y's. Thus the probability of N = 21/28 = 0.75, or 75 percent. The probability of Y is 25 percent.

Finally, making comparisons with control transitions that were nearly two months beyond the actual transition tends to underestimate the importance of the significance of the actual transitions, especially when some of the control transitions were in the holiday season. Three or four weeks beyond the actual transition would probably have been sufficient.

With the exception of the relatively high significance for the DST transition in October, 1974, the significances of fatality changes for most of the other DST transitions are somewhat low, and Section 7 showed that this is to be expected. Also, the calendar dates of the other transitions make them especially difficult to test for DST effects without high resolution in the data. Nevertheless, the overall consistency that appears in comparisons between real and control transitions suggests that the DST effect on traffic fatalities is probably a real one.

TABLE 9-1. STATISTICAL SIGNIFICANCE OF CHANGES IN FILTERED FATALITIES. Total U.S. Week of October 7,1973-May 5, 1974, 4AM-10AM. Bandwidth: 0.03 - 0.5 Cycle/Week.

Week (starting with week of October 7, 1973)	Probability (%) that random data would have given a larger change in fatalities	Sign of change
3	32	-
4*	16	-
5	28	-
6	91	-
7	39	+
8	1	-
9	56	+
10	73	+
11	65	-
12	37	-
13	87	+
14*	38	+
15	0	+
16	5	-
17	45	-
18	78	-
19	19	+
20	38	-
21	83	-
22	85	+
23	42	-
24	92	+
25	81	+
26	47	+
27	79	+
28	62	-
29	39	-
30	94	+

*Actual Transition

TABLE 9-2. STATISTICAL SIGNIFICANCE OF CHANGES IN FILTERED FATALITIES. Total U.S. Week of October 7,1973-May 5, 1974, 4PM-10PM. Bandwidth: 0.03-0.5 Cycle/Week.

Week (starting with week of October 7, 1973)	Probability (%) that random data would have given a larger change in fatalities	Sign of change
3	39	+
4*	31	+
5	24	-
6	48	-
7	19	+
8	2	-
9	77	-
10	83	-
11	64	+
12	74	+
13	6	-
14*	18	-
15	40	-
16	34	+
17	61	+
18	20	-
19	21	+
20	74	-
21	68	+
22	85	-
23	42	+
24	85	+
25	80	+
26	59	-
27	10	+
28	12	-
29	94	+
30	4	+

*Actual Transition

TABLE 9-3. STATISTICAL SIGNIFICANCE OF CHANGES IN FILTERED FATALITIES. Total U.S. Week of October 6,1974-May 4,1975, 4AM-10AM. Bandwidth: 0.03-0.5 Cycle/Week.

Week (starting with week of October 6, 1974)	Probability (%) that random data would have given a larger change in fatalities	sign of change
3	37	-
4*	4	-
5	50	-
6	92	-
7	66	-
8	19	+
9	76	+
10	36	-
11	67	-
12	23	-
13	40	+
14	55	+
15	14	-
16	43	+
17	82	+
18	71	-
19	53	+
20	20	-
21*	45	+
22	71	-
23	89	-
24	22	+
25	72	+
26	0	-
27	8	+
28	91	+
29	62	-
30	45	-

* Actual Transition

TABLE 9-4. STATISTICAL SIGNIFICANCE OF CHANGES IN FILTERED FATALITIES. Total U.S. Week of October 6, 1974-May 4,1975, 4PM-10PM. Bandwidth: 0.03-0.5 Cycle/week.

Week (starting with week of October 6, 1974)	Probability (%) that random data would have given a larger change in fatalities.	sign of change
3	76	+
4*	27	+
5	6	-
6	57	+
7	84	+
8	6	+
9	2	-
10	81	+
11	93	+
12	44	+
13	0	-
14	69	+
15	19	-
16	24	+
17	83	-
18	42	+
19	79	-
20	89	+
21*	41	+
22	73	-
23	70	-
24	64	-
25	74	+
26	72	+
27	35	-
28	47	+
29	72	+
30	40	+

* Actual Transition

TABLE 9-5. SUMMARY OF SIGN CONSISTENCY OF DIFFERENCES IN FILTERED FATALITIES FOR THE TWO TIME PERIODS: October 7, 1973-May 5, 1974 and October 6, 1974-May 4, 1975, 4AM-10AM. Total U.S. Bandwidth: 0.03-0.5 Cycle/Week.

Week Number	Sign Consistency
3	Y
4	Y
5	Y
6	Y
7	N
8	N
9	N
10	N
11	Y
12	Y
13	Y
14	Y
15	N
16	N
17	N
18	Y
19	Y
20	Y
21	N
22	N
23	Y
24	Y
25	Y
26	N
27	Y
28	N
29	Y
30	N

TABLE 9-6. SUMMARY OF SIGN CONSISTENCY OF DIFFERENCES IN FILTERED FATALITIES FOR THE TWO TIME PERIODS: October 7, 1973-May 5, 1974 and October 6, 1974 - May 4, 1975, 4PM - 10PM. Total U.S. Bandwidth: 0.03-0.5 Cycle/Week.

Weeks Number	Sign Consistency
3	Y
4	Y
5	N
6	N
7	Y
8	N
9	N
10	N
11	Y
12	Y
13	Y
14	N
15	Y
16	Y
17	N
18	N
19	N
20	N
21	Y
22	Y
23	N
24	N
25	Y
26	N
27	N
28	N
29	Y
30	Y

TABLE 9-7. SUMMARY OF SIGN CONSISTENCY OF DIFFERENCES IN FILTERED FATALITIES FOR THE TWO TIME PERIODS: October 7, 1973 - May 5, 1974, and October 6, 1974- May 4, 1975. 4AM-10AM and 4PM-10PM. Total U.S. Bandwidth: 0.03-0.5 Cycle/Week.

Week Number	Sign Consistency
3	Y
4	Y
5	N
6	N
7	N
8	N
9	N
10	N
11	Y
12	Y
13	Y
14	N
15	N
16	N
17	N
18	N
19	N
20	N
21	N
22	N
23	N
24	N
25	Y
26	N
27	N
28	N
29	Y
30	N

10. CONCLUSIONS AND RECOMMENDATIONS

This section summarizes the principal conclusions and recommendations of this study.

10.1 CONCLUSIONS

1. This report has presented evidence that DST reduces fatalities in motor vehicle traffic accidents by approximately one percent at low frequencies, and somewhere between one and two percent at combined frequencies. The DST hypothesis is also verified at all DST transitions and for inter-year comparisons.

2. There are indications that DST also reduces nonfatal traffic accidents and resulting injuries as well. However, because the temporal length of the injury data time series used in this study was very limited (and also had discontinuities), the relationship between DST and non-fatal accidents is not as well established as it is for fatal accidents.

3. This report has probably provided a first approximation to the magnitude of DST-related fatalities at low frequencies, but further analyses using the same data base (or modifications to it) do not appear to be justified technically, because neither the accuracy of the results obtained nor the conclusions derived are apt to change in any significant manner. Principal deficiencies in the data base used for this

study are omission of high frequencies, weekend and weekday fatalities not tabulated individually, and lack of variable time windows (e.g., 4AM-10AM vs. 6AM-10AM, etc.).

10.2 RECOMMENDATIONS

1. The principal recommendation of this study is that additional nonfatal accident data be acquired from selected States in order to quantitatively assess the effect of DST on motor vehicle nonfatal traffic accidents. Selection of data should be based on the criteria of representativeness, resolution, length of time series, appropriate dates, data quality, and data characteristics, as follows:

a. Representative data. A few States, in which a relatively large number of motor vehicle accidents occur, should be chosen from each of the four time zones.

b. Resolution. The data collected should reflect all reported accidents and should not be summarized to ensure that the (average) time interval between each accident is sufficiently small. This, in turn, will provide high frequencies which will be identifiable in the Fourier spectrum of accidents and the characteristics of the spectrum will be well-defined as a result.

c. Length of time series. Ideally, the length of the time series or amount of data collected for each year should reflect the full year, but six months at the least.

d. Dates. The data should include several spring and fall DST transitions, for the years 1972, 1973, 1974 and 1975.

e. Data quality. Data verification should include a reasonable amount of quality control, and all data should be stored on magnetic tape for ease and rapidity of subsequent analysis.

f. Data characteristics. This refers to the minimuim amount of information needed to satisfactorily describe each accident. Such information will permit appropriate stratification of the results of the analysis. Examples include date, time and type of accident (collision, non-collision, etc.) and age, sex and type of injured person (e.g., pedestrian, motorcyclist), etc.

2. The analyses developed in this study should be applied to any new fatality data acquired by the NHTSA, if the sampling interval is on the order of hours or less.

3. Consideration should be given to applying Fourier analysis and digital filtering to areas of highway safety other than DST because these methods have significant potential. Several possible areas of application are:

a. The general effect of daylight on the occurrence of motor vheicle accidents. This study would be a natural spin-off of the DST study.

b. Quantification of effects of the energy crisis. For example, using data obtained from the Fatal Accident File (FAF), a recent comparison of the frequency spectrum of fatalities for the first six months of 1973, 4PM-10PM, with that of the same period in 1974 indicated that the energy crisis did not substantially affect the number of weekly fatalities but did sharply curtail those classes of fatalities that occurred on a bi-weekly basis (possibly due to a reduction of non-esential trips, such as shopping trips on Wednesday and Saturday). Observations such as these could lead to certain conclusions about the travel patterns of people involved in fatal crashes, if the analysis were completed.

c. Identification of representative accident trends for specific road usage groups such as pedestrians, bicyclists, and motorcyclists.

d. Studying accident cause/effect relationships (specific factors causing accidents) by extending the application of Fourier analysis and digital filtering to, for example, (spectral) cross-correlation techniques and to those areas where exposure data are lacking. One possible application is identification of systematic trends in the relationship between accidents and weather.

e. Analyzing the effect of motor vehicle and highway safety program standards in reducing accidents and injuries on the highways.

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APPENDIX A. RELATIONSHIP BETWEEN MOTOR VEHICLE NONFATAL TRAFFIC ACCIDENTS AND DAYLIGHT SAVING TIME

It was not possible to analyze nonfatal injuries as completely as fatalities because, for this study, there were insufficient samples of nonfatal data available for Fourier transformations and digital filtering (see Section 5). Nevertheless, there are some indications that DST also reduces nonfatal accidents and resulting injuries.

By estimating the number of filtered injuries before and after a DST transition, it will be shown that these filtered injuries have greater statistical significance than the number of unfiltered injuries before and after transition.

The DST hypothesis does not discriminate between fatal and nonfatal traffic accidents, that is, between those killed and those only injured in these accidents (See Section 3). Therefore, the "filtered injury equivalents" of filtered fatalities were computed by first determining the ratio of the number of filtered fatalities to the total number of (unfiltered) fatalities for the 4 a.m.-10 a.m. time periods, one week before and one week after a transition, and then multiplying these ratios by the total number of injuries for the same periods; these calculations were repeated for the hours 4 p.m.-10 p.m. The results for the October 1973

transition are summarized in Table A-1. (Insufficient nonfatal data samples precluded analysis of the other DST transitions.)

Table A-1(a) is a contingency table consisting of the unfiltered injuries one week before and one week after the transition, for the intervals 4 a.m.-10 a.m. and 4 p.m.-10 p.m. The distribution of injuries before transition is tested against the distribution after transition. The null hypothesis is that there is no significant difference between the two distributions. (Comparison of injury data before and after a transition assumes that since many parts of the U.S. are represented, there should be no substantial differences except for the effects of DST.) Table A-1(b) tests the filtered injury equivalents before and after transition for the same time intervals. The null hypothesis is that there is also no significant difference between these distributions. Tables A-1(a) and A-1(b) have Chi-square values of 0.56 and 22.05, respectively. For one degree of freedom, the critical value of Chi-square, 3.84, is significant at the 5 percent level. Therefore, the null hypothesis is validated for unfiltered injuries but rejected for "filtered" equivalents. That is, following the October 1973 transition from DST to Standard Time, there were significant differences in (estimated) filtered non-fatal injuries, in accordance with the DST hypothesis. The interpretations for Table A-2 are similar to those for Table A-1.

The foregoing calculations are certainly not proof of a DST effect, since they are based on estimated data as a consequence of the limited availability of raw data, but they do provide some indication that DST probably reduces the occurrence of nonfatal accidents and injuries as well as fatal accidents and associated deaths.

TABLE A-1. SIGNIFICANCE OF FILTERED INJURY EQUIVALENTS OF FILTERED FATALITIES FOR DST TRANSITION IN OCTOBER 1973.

	One Week Before Transition		One Week After Transition	
	4AM-10AM	4PM-10PM	4AM-10AM	4PM-10PM
Unfiltered Fatalities	144	363	130	387
Filtered Fatalities	67	153	52	171
Unfiltered Injuries	4167	10685	4684	11787
Filtered Injuries	1939	4504	1874	5208

(a) Unfiltered Injuries

	One Week Before	One Week After
4AM-10AM	4167	4684
4PM-10PM	10685	11787

Chi-square = 0.56

(b) Estimated Filtered Injuries

	One Week Before	One Week After
4AM-10AM	1939	1874
4PM-10PM	4504	5208

Chi-square = 22.05

TABLE A-2. SIGNIFICANCE OF FILTERED INJURY EQUIVALENTS OF FILTERED FATALITIES FOR DST TRANSITION IN OCTOBER 1974.

	One Week Before Transition		One Week After Transition	
	4AM-10AM	4PM-10PM	4AM-10AM	4PM-10PM
Unfiltered Fatalities	124	310	102	328
Filtered Fatalities	56	106	34	132
Unfiltered Injuries	3769	9852	4229	9733
Filtered Injuries	1702	3369	1410	3917

(a) Unfiltered Injuries

	One Week Before	One Week After
4AM-10AM	3769	4229
4PM-10PM	9852	9733

Chi-square = 22.98

(b) Estimated Filtered Injuries

	One Week Before	One Week After
4AM-10AM	1702	1410
4PM-10PM	3369	3917

Chi square = 62.46

APPENDIX B. RELATIONSHIP BETWEEN MOTOR VEHICLE TRAFFIC FATALITIES AND THE FREQUENCY SPECTRUM

This section discusses possible applications of Fourier analysis and digital filtering to traffic accidents not associated with DST. Examination of all logarithmic power spectra for the intervals October 7, 1973 - May 5, 1974, and October 6, 1974 - May 4, 1975, shows that for the morning of the former interval, for the bandwith 0.03 - 0.5 CPW, the logarithms diminish in magnitude at a rate that is roughly inversely proportional to frequency. On the other hand, the fall off in the evening, for both years, is generally independent of frequency. These observations could lead to a better understanding of the characteristics of traffic accidents in general, for they imply different statistics. This independence of frequency implies a Markov process. The implication is that evening accidents are largely independent of one another whereas morning accidents may not be. Because evening travel involves far greater variation in trip purpose than morning travel, which is primarily work-oriented, the independence is understandable. On the other hand, the morning fatality population tends to be more uniform, hence there may be some interdependence between morning accidents. (Note: An accident is dependent if its occurrence depends on one before it, if not, it is independent. It should be noted that the

prime difference between morning and evening travel (as related to functional relationships between accidents) is in trip purpose rather than driver population mix. Thus, there tends to be the same driver mix in the mornings as in the evenings, but not the same trip purpose.) The logarithmic power spectra are described by the following (approximate) empirical equations:

$$A = [1 - \exp(-af)]/a \tag{B-1}$$

$$P = b \tag{B-2}$$

where A is the number of morning fatalities at frequency f, P is the number of evening fatalities, and a and b are positive constants. For small f (large periodicities), A = f. A does not decrease as rapidly with f for the interval October 6, 1974 - May 4, 1975. This could be related to the fact that there was no DST in effect at the beginning of 1975.

Although it is inappropriate to continue this line of inquiry for this report, it is likely that there are functional dependencies between different types of accident causation factors, driver populations and trip purposes.

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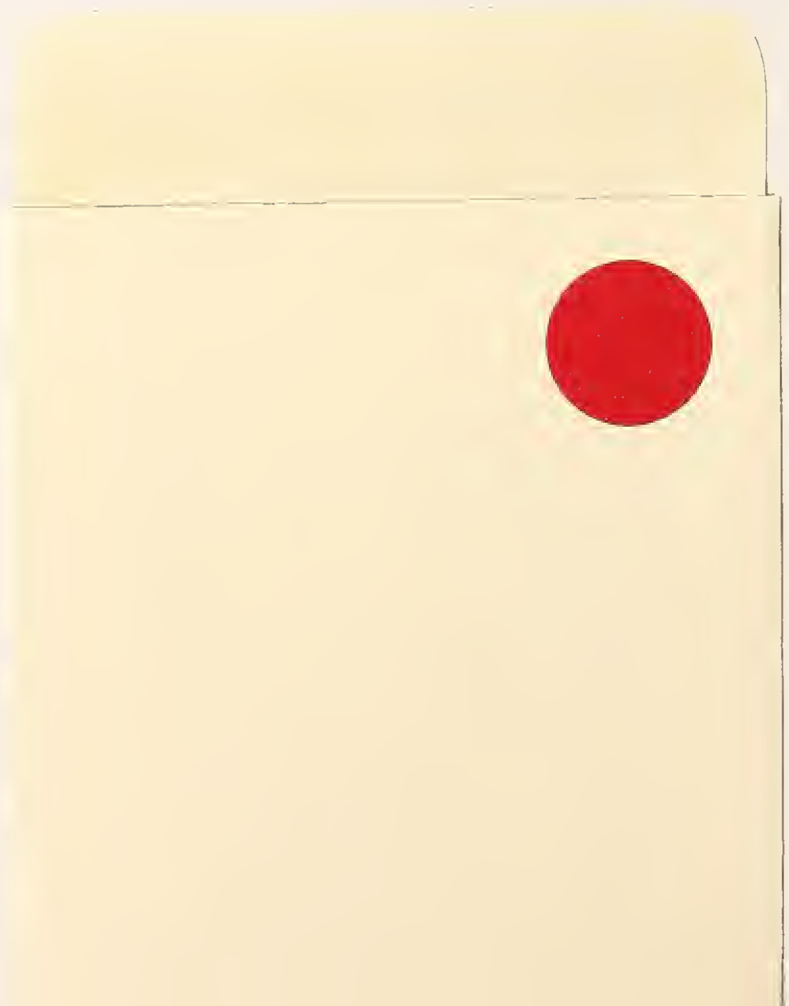

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